PLANNING FOREST ROAD NETWORKS

IN

BURMA

by

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ABSTRACT

Wood transportation methods in Burma are reviewed. Water transportation by rafting and floating is the most common method but is not practicable for hardwoods and teak logs must be dried to achieve flotation. The advantages of transportation of logs by trucks are noted.

The analytical procedures for planning forest road networks for the harvesting of wood are reviewed and an appraisal is made of their application for forest road planning in Burma.

The results of case studies to examine the feasibility of using analytical procedures to evaluate the efficiency of transport networks for the logging of compartments in the Prome Agency, Burma are presented. It was found that evaluation by a rigorous mathematical approach was not possible with the data extracted directly from records held in the Agency office. Anomalies in the data were noted and it is suggested that with more accurate data the procedures could be applicable.

The balance between road construction costs, road haulage costs and snigging costs was examined on the basis of the criteria that these should be equal. It was found that snigging costs were remarkably high with respect to road construction costs and it was concluded that the road network should be extended.

The conclusion was substantiated by trials of logging compartment with extended road networks. The results indicated that it would be economic to extend the road netowrk in all compartments examined.

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CHAPTER 1

WOOD TRANSPORTATION IN BURMA

1.1 INTRODUCTION

Wood has always been an important construction material and fuel in Burma. The first overseas exports of teak from Burma occurred not later than 1826 and with fluctuations have continued to increase in importance since that time. Wood production for both national consumption and export overseas is now an important sector of the total primary production in Burma and transportation of the wood is becoming more critical as a constraint on exploitation.

There are special geographical and institutional factors associated with the forest production and wood transportation. These are described as the background to the main aspect of this study, an examination of the planning and design of forest roading programmes and road haulage operations to expand the utilization of forests of Burma.

1.1.1 Geography and Topography

The Socialist Republic of the Union of Burma shown in Figure 1.1, is situated between $9^{o}\ 58'$ and $28^{o}\ 31'$ North Latitudes and $92^{o}\ 9'$ and $101^{o}10'$ East Longitudes. The maximum dimensions of the country are about 2,000 kilometres in a north-south direction and 800 kilometres east-west. The total area is 676,577 square kilometres.

Elevations in the western hills which rise near the Tibetan borderlands and run southward range up to 3,000 metres. The Tibetan mountains extend as the Kachin Hills in the northern tip of the country and the highest point in Burma, 5,900 metres, is Kokhaborazi near the Tibet border.

The Shan Plateau in the eastern part of Burma borders China, Laos and Thailand. The average elevation in this tableland is about 900 m but rises in some places to 2,700 m.

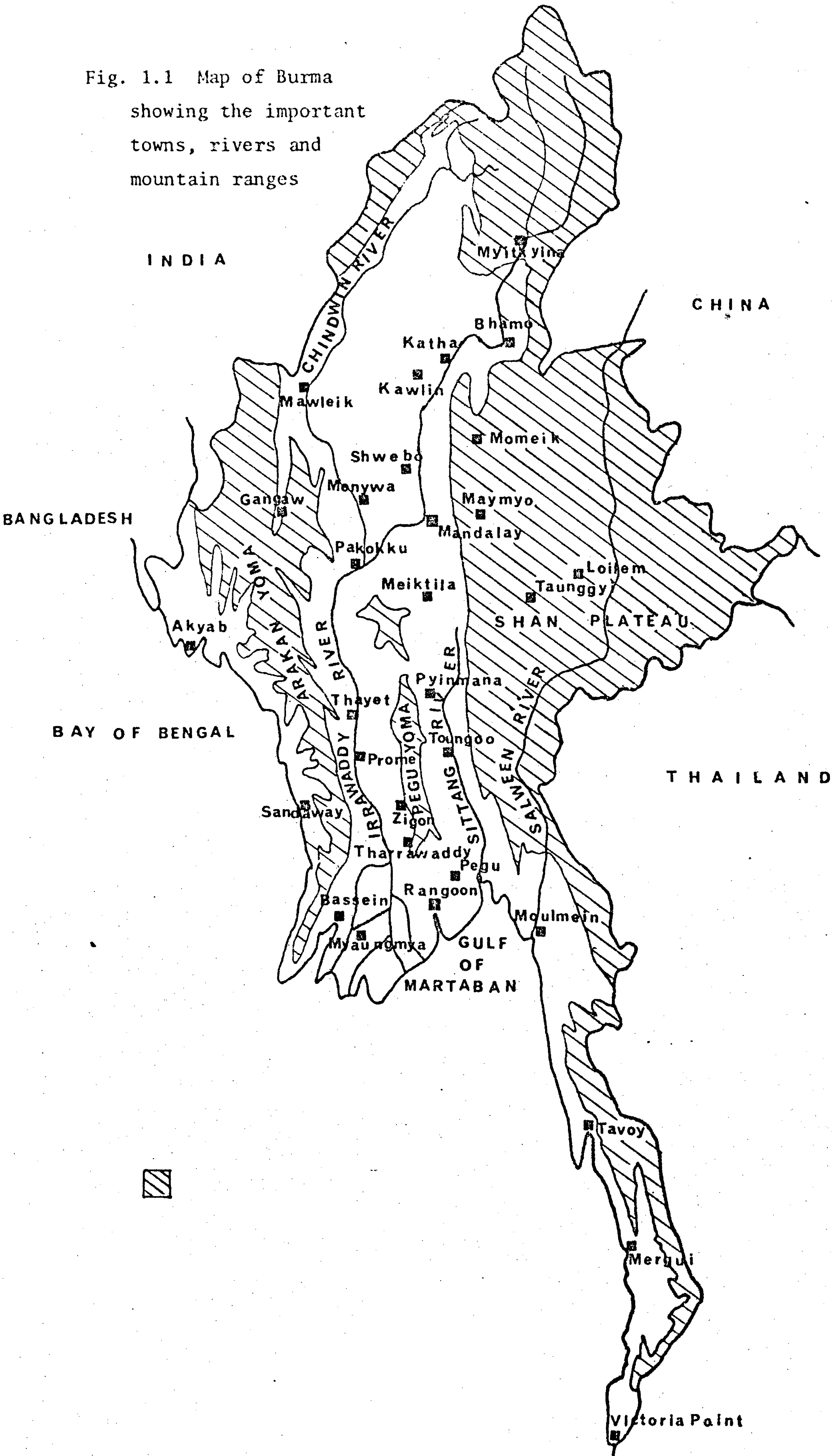
The Pegu Yoma Ranges running from north to south approximately through the middle of Lower Burma forms the watershed between the Irrawaddy and Sittang rivers. Elevations rarely exceed 610 m and decline to the south but rise sharply from the plains. The ranges form one of the leading timber producing areas of Burma and can be called the "Home of Teak".

There are four main rivers in Burma, the Salween, Sittang, Irrawaddy and Chindwin. They all run from north to south (Fig. 1.1).

Rising in Tibet, the wild Salween river crosses the Sino-Burma border, flows through the Shan Plateau and the Kayah and Kawthoolay States and discharges into the Gulf of Martaban at Moulmein. It is a swift flowing river and a great part of its course runs between steep and rocky banks. With notable concentrated falls it cannot be used for rafting in its upper reaches, but it is of great value as a timber floating stream. Teak logs are floated from the forests of the Shan, Kayah and Kawthoolay States. Log booms are located at Shwegun and Kamarmoung above Pa-an. The logs are sent to Moulmein as small rafts. The Salween river is navigable for about 90 km in its lower reaches.

The Sittang river originates near Yamethin and flows parallel to the lower Irrawaddy through the rich timber areas of Pyinmana, Toungoo and Pegu. It opens out into a wide estuary, noted for its tidal waves, in the Gulf of Martaban. The Sittang river is connected to the Rangoon river by the Sittang Canal which provides passage for motorboats and launches, and teak rafts can be towed by launches from Toungoo to Rangoon.

Fig. 1.1 Map of Burma showing the important towns, rivers and mountain ranges



The dominant physical feature of Burma is the great river Irrawaddy which originates in a major extension of the Himalaya Mountains. It flows for over 2,000 km through the middle of Burma to its mouth on the sea near Rangoon. It is navigable for about 1,400 km to Bhamo and is the main transportation link of Burma and the main rafting river. The main tributary of the Irrawaddy, the Chindwin, is navigable for about 700 km up to Homalin. While its course is impeded by shallows it is useful for rafting.

1.1.2 Seasons

There are three well defined seasons, the cold and dry, the hot and dry and the rainy or wet season.

(1) The cold and dry season

The dry season is from mid-October to mid-May with the cold period from mid-October to mid-February. Road construction can be commenced in October and log transportation by road in December. In some areas, especially in lower Burma, light rain can be expected in October and November and delays road construction in the forest. Skidding with animals is carried out throughout the cold season and it is the best time for mechanized forest operations.

(2) Hot and dry season

The hot and dry season occurs from mid-February to mid-May. Timber haulage from the forest to the sawmill or to an all-weather roadside is carried out in full swing at this time. Animal snigging stops in this season and it is the official resting period for Departmental elephants. The hot and dry season is also too hot to operate machines.

(3) Rainy or wet season

As a result of the south-west monsoon the well defined rainy season occurs from the middle of May to mid-October. Felling starts in late May followed by extraction by animals. This season is very good for extraction of wood and it is the busiest time for extraction operations. Teak logs are moved down the floating streams by the rise. The floating streams are patrolled continually during this season. However there is no road construction nor road haulage in the forest. The seasonal forest roads are washed out by the rain.

The rainy season is too wet and the ground is often too soft for machines. In some places forest roads are covered by mud.

1.1.3 The Forest Estate

The total forest area is 387,276 sq km or 57% of the total area of the country. The annual allowable cut (AAC) is presently 624,100 m^3 (345,800 log tons) for teak and about 3.9 million m^3 (2.17 million log tons) merchantable hardwoods. The exploitable volume per unit area in Reserved forest is about 2.29 m^3/ha (0.51 LT/ac) for teak and 12.29 m^3/ha (2.75 LT/ac) for hardwoods and is low when compared with the volume which is taken from other tropical forests in Southeast Asia, for example Malaysia 40.1 m^3/ha, Indonesia 49.0 m^3/ha (Anon. 1974). The total exploitable volumes for teak and hardwoods are shown in Table 1.1. The marketable hardwood species by groups is shown in Appendix 1.1. The grouping is for royalty assessment.

The distribution of forest types is shown in Figure 1.2 and the proportion in Table 1.2. Species commonly found in each type are given in Appendix 1.2.

Table 1.1 Annual Allowable Cut (AAC) for Teak and Hardwoods

Classification	TEAK				HARDWOODS			
	Area ha '000	AAC[1] m^3 '000	Yield/ha[2] m^3	Vol.cut/ha[3] m^3	Area ha '000	AAC m^3'000	Yield/ha[2] m^3	Vol.cut/ha[3] m^3
Reserved Forest	5,830	445.11	0.076	2.29	7,013	2873.7	0.410	12.29
Unreserved Forest	12,923	179.06	0.013	0.40	29,769	1050.1	0.035	1.06
Total	18,753	624.17			36,782	3923.8		
Average			0.033	1.00			0.107	3.20

1) Obtained by multiplying the number of yield trees, generally those 2.29 (7'6") gbh and over by a standard factor of 3.59 m^3 (1.99 log ton). The conversion factor determined by the State Timber Corporation depends on location and varies between 2.53 m^3 (1.4 LT) and 3.6 m^3 (2 LT)

2) AAC = area giving yield/ha/year over the whole forest

3) Volume per hectare available for extraction assuming a 30 year felling cycle.

Source: Appraisal of Forestry Project in Burma. Anon (1974)

Table 1.2 Forest Types in Burma

Forest Types	% of total forest area
1. Evergreen forests	
(a) Tropical wet evergreen (b) Tropical semi-evergreen	16
2. Mixed deciduous forests	
(a) Moist upper mixed deciduous (b) Dry upper mixed deciduous (c) Lower mixed deciduous	39
3. Deciduous dipterocarpus or Indaing forests	5
4. Dry forests	10
5. Hill and temperate evergreen forests	
(a) Sub-tropical wet hill forests (b) Sub-tropical hill savannah (c) Alpine	26
6. Tidal, beach and dune and swamp forests	4

Source: Forest Department, Burma

1. Evergreen Forest

This type occurs on the hill slopes of Arakan and Tenesserim coastal areas where the rainfall exceeds 2000 mm. It also occurs in shady valleys and places with a moist and cool aspect. The main species of commercial importance are kanyin (*Dipterocarpus* spp.), kaunghmu (*Anisoptera scaphula* (Roxb.),Pierre), kokko (*Albizzia lebbek*, Benth.), *pyinkado* (*Xylia dolabriformis*, Benth.), taungthayet (*Swintonia floribunda*, Griff.), thingadu (*Parashorea stellata*, Kurz), thingan (*Hopea odorata*, Roxb.), thitkado (*Cedrela toona*, Rorb.), thitpok (*tetrameles nudiflora*, R.Br.). Occurrence of

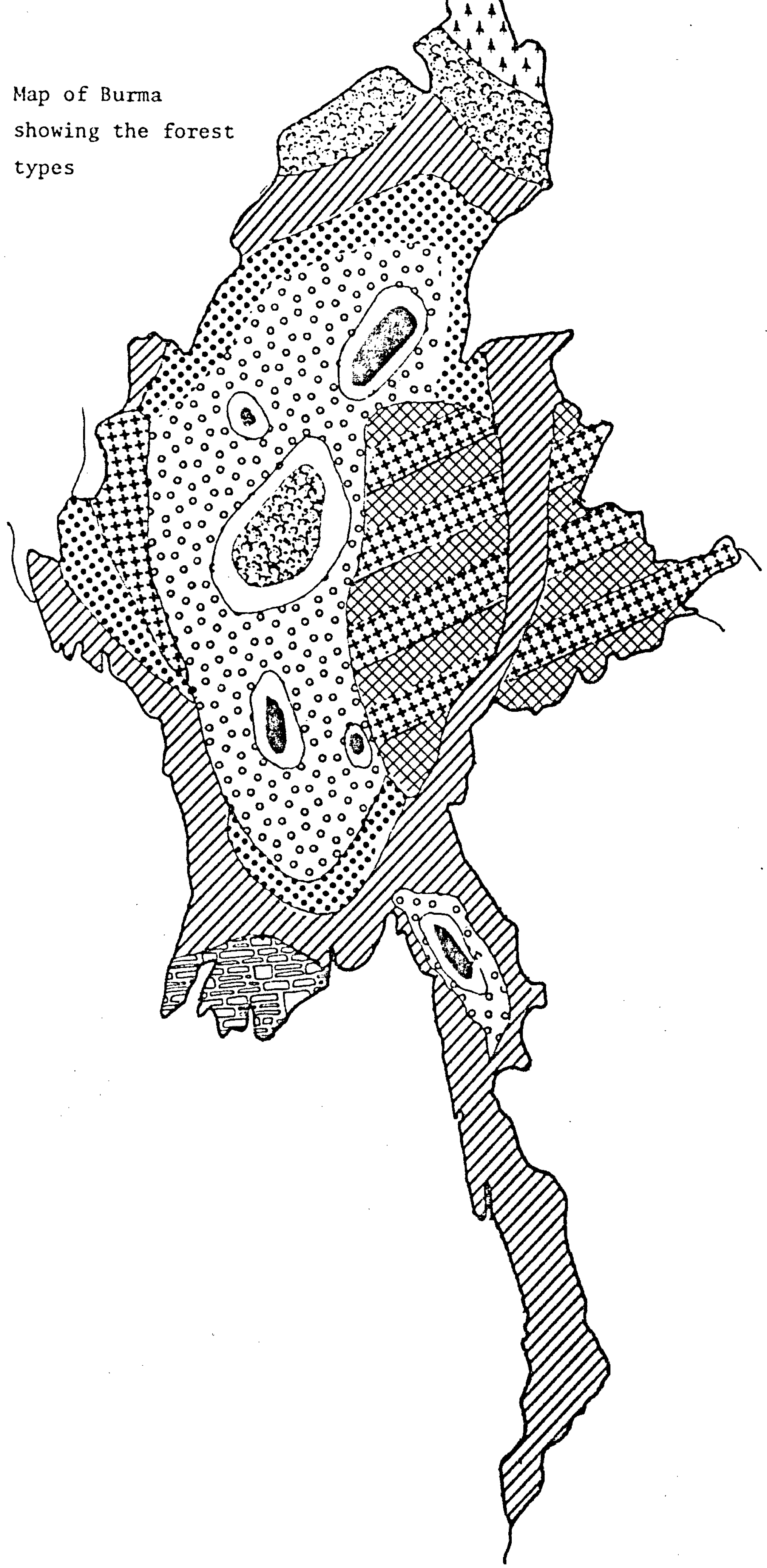


Fig. 1.2 Map of Burma showing the forest types

Legend to Fig. 1.2

(1) Evergreen forest
- Giant evergreen forest
- Riverine and typical evergreen forest

(2) Mixed deciduous forest
- Moist upper mixed deciduous forest
- Dry and lower mixed deciduous forest

(3) Deciduous Dipterocarpus (indaing) forest

(4) Dry forest

(5) Hill forest
- Hill evergreen and pine forest
- Dry hill forest
- Alpine forest

(6) Tidal, beach and dune and swamp forest

canes, evergreen climbers and bamboo species are characteristic of this type.

The evergreen forest is subdivided into tropical wet evergreen and tropical semi-evergreen. Both types contain a number of commercially important hardwood species such as pyinkado (*Xylia dolabriformis*, Benth) which is the most valuable hardwood.

The extraction season in the evergreen forest is in general a little longer than in the deciduous forest type but the period for road construction is less because the ground surface does not dry out as quickly.

2. Mixed Deciduous Forest

This is the most important from an economic point of view as the best quality teak (*Tectona grandis*, Linn. f.) and many other valuable hardwood species are present. It is subdivided as follows.

(a) Moist upper mixed deciduous (M.U.M.D)

(b) Dry upper mixed deciduous (D.U.M.D.)

(c) Lower mixed deciduous (L.M.D.).

The compartments selected for detailed study as described later in Chapter III occur in this forest type.

(a) Moist upper mixed deciduous forest

This type can be found over the greater part of the forest estate, generally on well-drained hill slopes where rainfall ranges from 1500-2000 mm a year. Common species are binga (*Mitragyna rotundifolia*, O.Ktze), didu (*Samalia insignis*, Schott and Endl.), letpan (*Bombax malabaricum*, D.C.), padauk (*Pterocarpus macrocarpus* Kurz.), pyinkado (*Xylia dolabriformis* Benth.), teak (*Tectona grandis*, Linn. f.), yemane (*Gmelina arborea*, Roxb.), Bamboos are kyathaungwa (*Bambusa polymorpha*, Munro) and tinwa (*Cephalostachyum pergracile*, Munro).

(b) Dry upper mixed deciduous forest

This type occurs on slopes and the tops of ridges of hills with a hot aspect and drier soils. Teak is generally the more abundant species but stems are smaller than those from the moist upper mixed deciduous forest. Other commercial hardwood species are (*Adina cordifolia* Hook. f.), in (*Dipterocarpus tuberculatus*, Roxb.), ingyin (*Pentacme siamensis* (Miq.) Kurz.), padauk (*Pterocarpus macrocarpus*, Kurz.), pyinkado (*Xylia dolabriformis*, Benth.), taukkyan (*Terminalia tomentosa*, W. and A.), thitya.*Shorea oblongifolia*, Thw.).

(c) Lower mixed deciduous forest

This type occurs on low-lying areas, usually with alluvial soils near streams, and where the rainfall is 1500 mm to 2300 mm. Common species in this forest type are leza (*Lagerstroemia tomentosa*, Presl.), pyinkado (*Xylia dolabriformis*, Benth.), taukkyan (*Terminalia tomentosa* W. and A.), teak (*Tectona grandis*, Linn. f.) and yon (*Anogeissus acuminata*, Wall).

These forests are very important from an economic point of view because they occur on accessible plains and the extraction and road construction costs for the teak (*Tectona grandis*, Linn. f.) and other valuable hardwood species are relatively low. Buffaloes are employed more commonly in this forest type area for the snigging of logs from the stump to landings or to floating streams.

3. Deciduous *Dipterocarpus* or Indaing Forest

This type occurs in drier areas where the soil is sandy or laterite. It is characterised by the presence of in (*Dipterocarpus tuberculatus*, Roxb.) which in some places forms pure stands. Common species are ingyin (*Pentacme siamensis*, (Miq.) Kurz.), thitya (*Shorea oblongifolia*, Thw.) and taukkyan (*Terminalia tomentosa*, W. and A.). The type varies from High Indaing with good stems producing saw timber to Scrub Indaing which is inferior with small and crooked boles.

The soil of this type of forest occurs as plains and presents the easiest road construction.

4. Dry Forest

These forests occur in the dry zone of the central part of the country, where the rainfall is less than 1200 mm. It is mainly thorny bush and does not produce saw timber. Commercially it is not important and there are no logging operations.

5. Hill Forest

These forests can be found at altitudes of over 900 m and are divided into three sub-types; dry hill forests, hill evergreen forests and the pine forests.

The dry hill forest occurs at about 1,000 m altitude. The commercial hardwood species are padauk (*Pterocarpus macrocarpus*,Kurz.), pyinkado (*Xylia dolabriformis*, Benth.), thitya (*Shorea oblongifolia*, Thw.), but extraction is very costly.

The hill evergreen forest occurs at about 1,000 m altitude and rainfall is generally 1200 mm to 1650 mm. Common species are oaks and chestnuts which are not timber yielding species. There is no extraction of wood from this forest type.

The pine forests occur above the hill evergreen forests. *Pinus khasya*, Royle), and *Pinus merkusii*, Jungh.), are the most common species. The areas are inaccessible and wood transport is difficult. Wood has been extracted for export to Japan but the cost and that of transportion to Rangoon is extremely high.

6(a) Tidal Forests

These forests occur along the coastal areas influenced by the tide and in the Irrawaddy delta. There is practically no commercial wood production from this type but the Irrawaddy delta forest is important for the supply of firewood to some of the larger coastal cities including Rangoon.

6(b) Beach and Dune Forests

These occur in exposed sandy areas along the coast and are characterised by the presence of kabwi (*Casuarina equisetifolia*, Forst.). There is no wood extraction from this type.

6(c) Swamp Forests

These occur in fresh water swamps near the main rivers and while not important commercially, roads are sometimes constructed through them to reach wood rich areas. It is easy to build roads when the surface dries out and the construction season must therefore be well chosen.

1.1.4 History of exploitation

Although commercial extraction of teak began early in the nineteenth century, it was not until 1860 that pressure increased to allow private enterprise to export teak on a larger scale (Anon. 1974). The Bombay-Burma Trading Company had been operating for some years, and to avoid a monopoly, four other European firms, Steel Bros., MacGregors, Foucars and T.D. Findlay were given 15-year leases for various teak forests all over the country, together with a right of renewal. These companies continued producing teak logs and sawn lumber for export markets until World War II (Anon. 1974). There were also some small traders and licensees but more than 75 per cent of total teak production was extracted by the five European companies. About half of the total teak extraction of the five companies was by the Bombay-Burma Trading Company.

The average annual extraction of dry teak during 1934-39 is shown in Table 1.3. The five foreign companies extracted 669,224 m^3 out of a total of 848,516 m^3, that is nearly 80% of the total wood extracted was by the foreign companies (Hoe, U. Chain, 1965).

Table 1.3 Average annual extraction of dry teak during 1934-39

Name of Company or Group	Average annual extraction 1934-39 (m^3)
B.B.T.C.	334,175
Steel Bros.	119,623
MacGregors	114,997
T.D. Findlay	46,343
Foucars	54,085
Company total	669,224
Contractors	22,115
Licensees	96,720
Government	56,385
Others	4,072
Total	848,516

Source: Burma Teak

While the foreign companies were granted long leases over forest land the trees were girdled for extraction by the Forest Department. Extraction was entirely by elephants and buffaloes and transportation mainly by waterway.

During the Japanese occupation from 1942-5, an estimated 700,000 teak logs were extracted by the Nippon Burma Timber Union. After re-occupation the Timber Project Board put the industry back on its feet (Anon. 1974).

Burma became an independent state in 1948 and during 1948 and 1949 private teak extraction and sawmilling enterprises were nationalized. The owners were paid compensation on the take-over. In order to continue the operations of the many private timber enterprises taken over by the Government, the State Timber Board was formed on 1 June 1948 (that name was changed to Timber Corporation in 1972) and given the sole responsibility for teak extraction and milling. It also became the sole agency for extracting and milling hardwoods in 1963 after hardwood extraction operations were nationalized. The Timber Corporation is now responsible for the whole of the timber industry in Burma.

During the 1960s the annual production of teak and hardwoods was about 450,000 and 900,000 cubic metres respectively. Due to an increase in local demand and foreign exports the production was increased to 595,650 m^3 of teak and 1,175,055 m^3 of hardwoods in 1977.

The harvesting and transportation of wood in Burma has been mainly by animal power for many years. Felling is done usually by manpower using crosscut saws and axes. Elephants and buffaloes are used in the snigging of logs from the stumps to the nearest point accessible for cheaper and easier methods of transport. That point may be a landing on a truck road, a floating stream or sometimes at a railway. If cart tracks can be made wood which is too heavy to float is transported by carting to the nearest sawmill or railway siding. Carting is also used in teak extraction in some areas where a floating stream is situated some distance from the felling site.

Before World War II the number of elephants, 6500, was sufficient for the extraction of wood but they dropped to 3500 and are now insufficient for extraction.

The harvesting and transportation of wood was extended and some mechanical equipment was introduced into the logging operations in 1954-55 to supplement animal and manpower. Chainsaws for felling, skidders and tractors for snigging, bulldozers for road construction and trucks for transportation are all used but manpower, animal power and water transport are still the main factors of harvesting and transportation.

While the main purpose of this study is to examine forest roading and road haulage and to optimize the factors of road construction, extraction and road haulage in the design of a compartment harvesting operation, it is noted that any increases in efficiency in these three factors would entail increased felling if the gains are translated into increased wood production. While problems associated with road construction, road haulage and extraction are discussed in detail later, the felling operation is not. Brief comments on the difficulties encountered in improving felling productivity and in sustaining production are therefore made at this point.

Teak trees which attain 2.29 m (7'6") in girth at breast height (Section 1.1.5) are girdled for exploitation while the girth limit for hardwoods varies from 1.52 m (5'0") to 2.43 m (10') at breast height. The girth to be cut is much bigger than that at breast height because trees must be felled as low to the ground as possible in accordance with the rules and regulations of the Forest Department. Certain trees have substantial buttresses but it is not allowed to cut above the buttress. The section immediately above the buttress has no value and is cut off after a tree is felled and left in the forest. Only forty to sixty per cent of a felled tree can be marketed.

The production per hour by fellers is determined by the diameter and the number of logs per tree. The diameter affects production in two ways (FAO 1974). It determines the amount of work needed to fell a tree (i.e. the area to be cut through), and it reflects the volume that might be utilised. A large tree will require more time to be felled and cut into log lengths but it will also give a higher volume of timber. Though a tree with a large buttress will need more time to be felled it may not give a higher volume of timber, in which case the production of felling per hour or per day would be low.

There is a problem to get fellers in some areas in Upper Burma (e.g. Momeik Agency). Fellers must be collected from distant localities but they are not usually willing to go for a long time. To solve the felling problems departmental fellers using power saws were introduced in the late 1960s. Training is necessary for skill and efficiency of fellers and the training of chainsaw operators was introduced in Upper Burma.

There is no doubt that the power saw is a good piece of equipment for tropical high forest logging (FAO 1974). Both one-man and two-man saws are in use but the two-man saw seems to be gradually losing ground. It is found today exclusively on the bigger landings. The one-man power saw with a fairly long cutter and of some 7.46-8.95 kw power is the most suitable type (FAO 1974).

However crosscut saws which are very cheap in capital cost when compared with power saws are still the most widely used in the logging operations of Burma. Rapid expansion of production may require the replacement of crosscut saws with chainsaws as additional labour for crosscutting by manpower may not be available.

1.1.5 Organisation and management of forestry sectors

Forestry operations are carried out by the Forest Department and the State Timber Corporation. Operations from seeds to mature trees are done by the Forest Department, that is the Forest Department has responsibilities for wood growing. The Timber Corporation has, in general, responsibilities for felling, logging, transportation, milling and marketing.

Girdling of teak and Selection Felling (SF) markings are done by the Forest Department. Girdling of teak trees is undertaken so that about three years after girdling the standing wood has dried out and with a density less than that of water can be floated downstream to the rivers where there are rafting depots.

Teak trees which attain 2.29 m (7'6") in girth at breast height in good forest and 2.0 m (6'6") in poor forest are girdled for dry teak extraction. For green teak and hardwoods, S.F. markings are done instead of girdling. The girth limit for hardwood exploitation varies from species to species (1.1.4).

The number of trees and their girths at breast height are recorded in the girdling and SF marking notebooks together with maps 1:15840 (4" to the mile) on which the positions of the trees are shown. The girdling and SF marking notebooks are completed by the Forest Department and passed to the Timber Corporation.

The forest land is classified as Reserved and Unreserved or Unclassed Forest. Reserved forests are divided into compartments which are about 2-3 sq km in area. Unclassed forests are divided into coupes. Girdling and SF marking reports are prepared compartment by compartment or coupe by coupe as they become due for exploitation.

The harvesting and transportation of wood from the forest to sawmill or to the timber depot at Rangoon is carried out by the Extraction Department of the Timber Corporation. A General Manager is Head of the Department and with a Deputy General Manager for planning and a Headquarters Manager is located at Rangoon. Thirty five Agencies are located throughout Burma and the Agency Managers are under four Deputy General Managers called Divisional Managers. The Divisional Managers are located at Rangoon, Toungoo, Mandalay and Monywa. The organisation chart of the Timber Corporation is shown in Appendix 1.3.

Under the Agency Managers, there are Deputy Managers in charge of Ranges. The number of Deputy Managers in an Agency is not fixed because it depends on the volume of timber and the number of Ranges. In Paukkhaung Range, Prome Agency, the number of staff for the production of 28,000 m^3 of dry teak, 3,600 m^3 of green teak and 18,000 m^3 of hardwood is as follows:

Deputy Manager	1
Assistant Manager	3
Timber Ranger	4
Chaung-oke	8
Chaung-gaung	10

The compartments selected for detailed study, as discussed later, are in the Paukkhaung Range.

1.1.5.1 Planning extraction operations

The girdling notebooks prepared by the Forest Department are passed to the Timber Corporation. The Manager of the Timber Corporation therefore knows the girdling balance and the area. Planning for logging to meet the required volume of wood is undertaken with the Manager choosing suitable compartments.

The exploration surveys are usually done one year ahead of the logging operations. The exploration is very important for the success of the subsequent operations and seventy five per cent of the trees to be felled are inspected thoroughly. The girdling and SF marking notebooks prepared by the Forest Department and passed to the Timber Corporation are the basis for the exploration.

Planning for logging is undertaken compartment by compartment. Compartments are often adjacent to each other. The following points should be considered in the exploration.

(1) Distribution of girdled or marked trees

Girdled or SF marked trees may not be evenly distributed because girdling or SF markings are controlled by girth limits. Girdled teak trees are usually more scattered than the marked hardwood species. The average distribution of girdled teak is 2.5 trees per hectare.

(2) Size and quality of girdled or marked trees

The size of each tree is shown in the girdling or SF marking notebooks but that measurement is the girth at breast height. A tree can be poor in quality though the girth is large. Some big trees may have defects such as hollows along the pith.

(3) Estimated volume of timber

Girdled or SF marked trees are inspected in the exploration and the average volume of timber per tree or total volume in the whole compartment can be estimated. For dry teak the following table is used to estimate timber volume.

Girth at breast height	Estimated volume per tree
1.22 m (4'0") to 1.80 m (5'11")	1.44 m^3 (40 cu ft)
1.83 m (6'0") to 2.11 m (6'11")	2.16 m^3 (60 cu ft)
2.14 m (7'0") to 2.42 m (7'11")	2.53 m^3 (70 cu ft)
2.44 m (8'0") to 2.72 m (8'11")	3.97 m^3 (110 cu ft)
2.75 m (9'0") and over	5.78 m^3 (160 cu ft)

The accuracy of the estimate can vary from 5% to 10% depending on the quality of forest but previous fellings in adjacent areas can help in ensuring an appropriate accuracy for the estimate of the volume to be extracted.

(4) Flora and fodder for animals

Young bamboo leaves and grass are good fodder for buffaloes while elephants like some kind of climbers, bamboo shoots and leaves. If sufficient fodder is not readily available for grazing in the working compartment or coupe then the buffalo and elephant must be travelled further with a consequent decline in productivity.

(5) Availability of water

The usual practice is for extraction crews (elephant riders and buffalo men) to camp on a stream bank in the working area. Water is very important for animals, for drinking and for bathing. Buffaloes like to stay in the water after they have worked and sometimes prefer to stay in the mud. Elephants are allowed to graze during free hours and at night. In the early morning a mahout has to find his elephant in the jungle and wash it before the dragging gear is fitted. Any dirt on the back of an elephant may result in abrasion and sores from the harness during working hours. Water is also important for workers in the jungle because they stay close to the working site. There must always be an attendant with an elephant that stays in the jungle and mahouts staying in the jungle throughout the year must be able to obtain water. Information regarding availability of water in the dry season is usually obtained from local villagers.

(6) Creeks

Small creeks will usually be used as dragging paths if animals are able to go along them. Each creek must be inspected to see whether it is, for example, rocky and has waterfalls or can be used readily as a dragging path. It may for example be necessary to blast out rocks and the required amount of dynamite should be estimated. The positions and characteristics of the creeks are thus very important in planning the extraction network. Creeks are shown on the maps prepared by the Forest Department but the utility for extraction must be assessed by Timber Corporation staff. Finally, it is important in the assessment of creeks to ensure that the dragging paths join at a convenient landing.

(7) Floating streams

Streams in the working area can be used as floating streams for dry teak if the height of flood level, which can be observed by debris marks, is about one metre.

Stream clearing may be necessary before the logging operation commences. Fallen trees in the stream, or trees likely to fall into the stream are felled and dragged away. Obstructions in the stream such as stumps and rubbish are collected and burnt.

(8) Topography

The slope of the ground is a most important parameter in planning for the extraction of wood but at present the only information obtained in the exploration survey is the classification of the main ridges into steep or gentle. This is done by visual observation. This limited qualitative information is insufficient for planning of road layouts and the topographical survey information that should be obtained in connection with the exploration of the area is discussed later.

(9) Measuring points (also called landings)

Logs extracted from the stump are placed at landings or measuring points for further transportation. Measuring points are required where the distance from the stump to the delivery point is relatively long and it becomes more convenient to bring logs to a landing or staging point at which they can be measured.

(10) Delivery points

Delivery points may be on a bank or in a stream in which the logs can be floated. They can also be at sawmills, railway stations and timber depots. The delivery point is a critical factor in determining the layout and direction of the skidding operations in a particular compartment. Perhaps the most critical decision associated with the selection of the delivery point is in regard to the choice of the method of transportation, that is water or road transport. Such a choice cannot usually be made on a compartment by compartment basis and should be determined prior to the detailed exploration of a compartment. The criteria for determining the major transport method, water or road, are discussed later. However in most extraction areas the logs are now moved by truck to delivery points and information for road planning is therefore usually required.

(11) Extraction power

The elephant or buffalo power required for dragging of the logs from the stump to the landings or floating streams must be estimated. In difficult areas where the slopes are steeper than about 25^{o} and the small creeks are so rocky that a pair of buffaloes cannot work side by side, elephants are used for stumping. In flat areas buffaloes and mechanical units are used.

An elephant's annual working capacity, that is for one season, is about 270 m^3 (150 LT) to 360 m^3 (200 LT) for teak and 360 m^3 (200 LT) to 450 m^3 (250 LT) for hardwoods. However, the number required will depend not only on the volume of wood but also the length and topography and the capacity of the animals.

The estimated volume of wood is determined in the exploration for each compartment (Section 1.1.5.1(3)). The estimated volume of wood is divided by the estimated working rate of the animals to give the number of elephants required in that compartment.

The effectiveness of the exploration surveys is very dependent on the experience and skill of the field officer undertaking the survey. There are no written guidelines for exploration surveys and it is suggested that they would be very useful for the preparation of exploration reports, particularly when transportation of the logs by road may be more appropriate than by water for then more detailed information on the possible routes would be necessary. Preparation of the guidelines should be part of pre-exploration planning.

It does seem that insufficient consideration is given to maintaining, in the case of compartments where road transportation is adopted, a balance between snigging, road construction and road haulage. This is the major aspect investigated in this study and recommendations are made later regarding guidelines for exploration surveys where road transport is a possible option and are associated with the criteria for determining the major transport method, water or road.

1.1.6 The need for expansion of the timber industry

The economy of Burma depends primarily on the agricultural and forest sectors. Export of forest products, mostly teak, has always been a major source of foreign exchange earnings ranking second to rice in value. Most of the teak production is exported either in the form of logs or as conversions. Hardwood exports are mostly in the log form. Exports by commodity are shown in Table 1.4.

Table 1.4 Exports by type of commodity

Serial No.	Type of commodity	1961-2	(Kyats X 10^4) 1971-2	1972-3	1975-6
1	Agricultural products	10,706	4,398	3,327	7,839
2	Forest products	1,349	1,547	2,090	2,870
3	Mineral products	526	656	687	730
4	Animal & marine products	31	23	44	43
5	Others	56	20	104	161
6	TOTAL	12,668	6,644	6,252	11,643

Source: Report to the people 1977-8

The Timber Corporation has been unable to meet its export commitments because of production problems. Between 1969 and 1972, only 50% of the contracted log sales and 68% of the conversions were actually shipped (Anon. 1974). Details of Burma teak exports between 1967 and 1972 are shown in Table 1.5. More up to date information is not available.

Domestic lumber sales are mostly hardwoods since teak production is geared towards the export market. Statistics of recent years show that about 30% of the teak and 97% of the hardwoods (roundwood equivalent) produced in Burma were consumed within the country (Anon. 1974). However current output satisfies only about 60% of the requirements (based on written orders). The remaining 40% of orders are therefore left unfulfilled. Projections of timber requirements formulated by the Ministry of Planning and Finance are shown in Table 1.6.

Table 1.5 Exports of Burma teak by destination

	1967/8	1968/9	1969/70	1970/1	1971/2
					(Logs m^3)
U.K.	4,841	4,446	3,680	7,128	5,433
W. Germany	15,508	17,227	11,146	19,938	17,043
Denmark	20,207	18,582	13,877	17,794	14,857
Holland	5,808	4,186	3,401	4,471	2,809
Sweden	3,280	3,224	2,421	3,513	2,666
Singapore	-	1,323	5,695	3,312	3,458
Hong Kong	1,504	4,222	1,066	1,076	477
Japan	2,439	5,653	5,606	13,979	27,364
Middle East	-	-	-	-	-
Rest of World	18,025	21,537	10,072	17,411	11,158
Total logs	71,612	80,400	56,964	88,622	85,265
					(Conversions m^3)
U.K.	14,137	12,019	8,104	9,612	8,424
W. Germany	1,978	3,074	1,688	2,463	3,169
Denmark	15,341	19,339	12,278	9,343	15,929
Holland	4,731	4,041	2,740	2,171	1,271
Sweden	9,666	12,196	9,671	5,857	6,740
Hong Kong	30,017	39,313	32,290	41,907	31,990
Singapore	20,445	25,788	24,687	19,897	23,721
Japan	903	1,809	1,608	2,686	204
Middle East	-	-	-	-	-
Rest of World	29,614	36,360	53,013	42,161	40,268
Total conversions	126,830	153,939	146,079	136,097	131,716

Source: Timber Corporation

Table 1.6 Local requirements of sawn timber

(thousand m^3)

	1976	1977	1978	1979	1980
Teak	75	79	82	85	88
Hardwoods	836	862	886	913	938
Total	911	941	968	998	1026

Source: Appraisal of Forestry Project in Burma, Anon (1974).

The world requirements for industrial wood have been estimated to grow at an average rate of 2.7 per cent per annum between 1962 and 1975, and at 3 per cent per annum during 1975-1985, to reach almost two billion cubic metres per year by 1985 (Takeuchi, 1974). The world demand outlook for teak and hardwoods is very promising (Anon. 1974).

Production of teak and hardwoods in Burma is shown in Table 1.7. Production has not increased significantly from year to year but the population has increased and per capita consumption has therefore decreased. However, the increasing population calls for a steadily increasing volume of construction timber and it is desirable that there be continuing efforts to increase the production of both teak and hardwoods.

Many tropical hardwoods were once considered unsuitable for pulping or fibreboard production but new chemical and semi-chemical pulping methods have increased the range of tropical hardwoods that can now be used. A high proportion of the paper used in Burma is imported. The only paper produced in Burma is from a small mill which uses bamboo, and now that the processes are available for using a large number of local species it would be feasible to supply a paper mill which would save the costs of imports. Import savings would be an advantage to the economy. However it is necessary to demonstrate, inter alia, that the capacity and expertise to supply wood to the mill can be developed. It would also help a pressing foreign exchange shortage if the forestry sector could earn more foreign exchange. In order to earn more foreign exchange from teak, efforts must be made to reach maximum production. Hardwood production could also be increased both for local consumption and for export as the national and world demand for hardwood is favourable.

Table 1.7 Production of teak and hardwoods (m^3)

Year	Teak	Hardwood
1939-40	806,347	863,181
1947-8	468,480	702,339
1961-2	451,250	1,653,380
1964-5	514,425	1,510,785
1968-9	543,305	1,642,550
1969-70	543,305	1,646,160
1970-1	653,410	1,675,040
1971-2	525,700	1,874,340
1972-3	554,921	1,817,698
1974-5	465,339	1,562,893
1975-6	427,487	1,415,060
1976-7	505,400	1,505,370

Source: Report to the People 1977-78

The amount of teak which could be harvested annually in Burma, without affecting sustained yields, is estimated at 624,100 m^3 (Section 1.1.3) but in recent years teak extraction has averaged only about 541,500 m^3 (Table 1.7), resulting in a serious backlog of some 700,000 ripe girdled teak trees (about 2.5 million m^3) that are no longer putting on increment and are standing unextracted. Marketable hardwood species are also left in the forest because the harvested volume of wood is lower than the annual allowable cut.

Increased production entails better or expanded logging methods and this has presented considerable difficulties for there is not ready access to mechanical equipment.

1.1.7 The limitations of the existing transport system

While there are compelling reasons for expansion of the timber industry there are of course many practical difficulties to achieving significant expansion. The limitations of the existing transport system is one difficulty, perhaps the most significant.

Transportation of wood is by water or truck from the landings to sawmills, railheads or timber depots. Water transport is the most important and almost all dry teak is transported by this method. The actual quantity transported by water, road and rail is not available. However, 82% of teak arrivals were by water in 1970/71. Hardwood logs were transported in 1970/71 as follows; by river 18%, by rail 22% and by road 60%. Many of the delivery points are located in positions which are convenient for water transport and, together with cost factors, will ensure the continued dependence on water transport for the delivery of logs. However, the capacity to move the wood by water is not unlimited and there are considerable disadvantages which are discussed below. Rapid expansion of the timber industry may therefore require emphasis on the other forms of transport, road and rail.

The major disadvantage associated with increasing the rate at which logs are transported by water would be the continued requirement for girdling, the unreliability of delivery time of logs to the mills and the losses which occur in water transport.

Until recently the difficulty of transporting teak logs from the forest has been met by the longstanding practice of floating the dry logs down the numerous rivers and streams. The method is usually seasonal as many streams dry up for long periods each year. However as teak extraction moves further back from the larger rivers, river transportation is becoming more difficult; in many areas uneconomic and in some impossible. The dry teak logs do not always arrive at the main rivers during the same year they are placed in the floating streams. While they may float down in subsequent wet seasons there is often a long time lag between the logs entering the streams and delivery. It normally takes three to four years for logs to be transported from forest to mill or depot and deterioration of teak quality occurs during this period.

The log losses in water transport, particularly in the floating streams before reaching the main river, are considerable. Table 1.8 shows the losses and the outturn, that is the logs arriving at main rivers from the streams.

Hardwood and green teak logs do not float and must therefore be trucked out from the landings to the sawmills, railway sidings or timber depots. However inadequate forest roads and insufficient trucks have limited the extraction of these logs, for example, thousands of hardwood logs were left at landings during 1967 and 1972 (particularly in Kama Range, Thayet Agency) and were damaged by fungus and weather.

Table 1.8 Transportation of logs by water

Year	Opening neap	Input of new logs	Total for outturn	Outturn Logs	Outturn %	Losses Logs	Losses %
1949/50 to 1953/54	338,015	89,215	427,230	69,693	16.3	18,662	4.3
1954/55 to 1958/59	342,315	214,691	557,006	158,910	28.5	58,383	10.4
1959/60 to 1963/64	329,303	354,205	683,508	316,777	46.3	21,239	3.1
1964/65	410,242	368,621	778,863	322,530	41.4	-	-
1966/67	453,633	369,645	823,278	332,411	40.3	68,593	8.3
1967/68	422,274	385,297	807,571	381,543	47.2	36,394	4.5
1968/69	389,634	439,635	829,269	345,874	41.7	51,361	6.1
1969/70	432,034	498,828	920,862	442,805	47.5	28,050	3.0
1970/71	459,998	475,600	935,598	451,200	48.2	-	-

For many years timber carts were the usual means of transport for all wood too heavy to float. However in past years the working sites for extraction were not very far from the sawmills or railway sidings and the carting method is disappearing as extraction operations move further from the existing sawmills. Other means of transport must therefore be found, particularly as the buffaloes formerly used in this work are now required for snigging as the number of elephants available for extraction has dropped.

It is clear that there are significant limitations in the existing transport system at national, regional and local levels and that these limitations present difficulties for the expansion of production. There are some indications that the limitations of the transport system are the most critical determinants of production. This is one of the main reasons that this study programme was initiated.

In the next Section the existing transportation methods and systems are reviewed in more detail to provide the background for an assessment of their efficiency and limitations.

1.2 TRANSPORTATION METHODS AND SYSTEMS

1.2.1 Introduction

The most common transportation method in Burma is elephant extraction and water transport. In this section the various methods of extraction are discussed and reviewed in relation to an assessment of the efficiency and capacity of the total transportation system.

1.2.2 Extraction

After completing stump operations, logs are taken to a floating stream or to a roadside landing. Usually logs are dragged by buffaloes or elephants. There are a few skidders and carts are still used in some places.

Buffaloes

Buffaloes are available for skidding at nearly all forest sites. Their large splayed feet enable them to pass over soft ground. They are sometimes used in carting for a short distance of up to 10 to 15 km. Their only disadvantage is their slow movement and small individual output, but they can work in a team of up to ten as in Plate 1. They have a much

Plate 1: Team of Buffaloes

Plate 2: Pair of Buffaloes

greater pulling capacity in the rainy season than in the dry season. There are two reasons; reduced friction between the wet ground and the log and they are more energetic in the wet weather.

Buffaloes usually work five days a week and about six months a year. Buffaloes belong to farmers and are available for forestry work only during the seasonal gaps in farm work. Their working hours per day are low, about five or six in the morning, and they graze for the remaining daytime. They are not fed but find their own food.

The best work is done by two buffaloes side by side as in Plate 2, but this is not possible without clearing a wide skidding path. The buffalo-men have to prepare the snigging paths.

The average output by a pair of buffaloes is about 90 m^3 for a working season from say July to January or February. Although they can work in a team only short logs of large diameters can be dragged. The maximum volume of a log to be dragged by buffaloes is about one cubic metre. There are heavy financial losses as a consequence because foreign markets accept short logs only with considerable price deductions.

While the cost of extraction per unit volume by buffaloes is only about 75% of elephant extraction costs they are usually employed only in flat areas. They can work on slopes up to 25^o.

It appears that the work of buffaloes will continue for many years in the logging operation of Burma, for machines cannot be imported to replace the draught animals. Table 1.9 shows the number of working buffaloes used in the extraction of timber in Burma.

Table 1.9 Number of buffaloes

Particulars	Unit	1964-5	1970-1	1972-3	1974-5	1975-6	1976-7
Public	No	Nil	Nil	Nil	Nil	Nil	Nil
Private		20,958	15,280	14,940	8,602	8,603	5,665

Elephants

Elephants are one of the most interesting animals. They are quite intelligent and learn quickly. Once they have been trained, they can do what they are asked.

The training of elephants starts at the age of 5 years and it is usually done in the cooler weather. They are used as baggage elephants up to fourteen years of age and then they are attached to working camps and trained to drag logs. Full time work begins at the age of eighteen and continues until 50 or 55 years, even more if the elephant is in good condition. The extraction of timber depends mainly on elephants. For example, in Compartments 41,42,43 and 44 for which data was collected for this study only about 3% of timber was taken out by buffaloes. Details are presented in Chapter 3. In some areas like North Nawin Range in the Prome Agency, where the terrain is most rugged, only elephants are used in the extraction of logs.

Elephants either drag the logs from the breast by means of special harness (Plate 3) or if it is more convenient they push them with their heads or tusks (Plate 4). They turn the logs, when necessary with their tusks, by which they level and push the logs downhill. In India, the elephants are not harnessed to the logs when they are to be taken down

Plate 3: Elephant dragging log with special harness

Plate 4: Elephant pushing log with tusk and trunk

steep slopes. A bark rope is attached to the log and the elephant pulls by holding the other end in its teeth. Elephants used in this way suffer injuries to and decay of the teeth.

Elephants must also be used to transport rations to the working areas in the rainy season, as there is no other means. The use of elephants in the transportation of rations reduces the capacity for extraction. If security is favourable, rations should be taken to the base camps during the dry weather using bullock carts or even elephants as they are free in the dry season. In Burma the average yearly output of elephants is 270 m^3 to 360 m^3 per head for teak and 360 m^3 to 450 m^3 per head for hardwood. In Thailand, the yearly output is given as 200 m^3 to 300 m^3 and in India and Pakistan, it may be only 150 m^3 a year (Cermak and Lloyd, 1962). Burwell (1958) estimated that in Ceylon, the daily output was about one cubic metre skidded for a distance of 1.6 km and an output of 4.5 m^3 per day for a skidding distance of 410 m.

The number of elephants available for extraction of timber is not sufficient to meet the demand because they were depleted during World War II when the number dropped from about 6,500 to 3,500 and has not been built up since. The number of elephants are shown in Table 1.10.

Table 1.10 Number of elephants

Sector	1964-5	1970-1	1972-3	1974-5	1975-6	1976-7
Public	-	1,045	1,112	1,149	1,191	1,199
Private	-	2,245	2,515	2,093	1,798	1,714
Total	3,051	3,290	3,627	3,242	2,989	2,913

Mechanical extraction

The worldwide trend is towards the use of machines for extraction and there are a large number of options in selecting machines for the extraction of timber. In Burma only a few machines have been introduced, all since 1954/55. Crawler tractors and rubber-tyred skidders are used in some areas but there are no forwarders or cable system haulings. Table 1.11 shows the number of machines.

Table 1.11 Number of machines

Machine Type	1964-5	1970-1	1972-3	1974-5	1975-6	1976-7
Skidders			50	50	50	109
Tractors	30	129	92	92	92	124

Expensive extraction machines can be used profitably where they can be worked at their full capacity and this can be readily achieved only where a large amount of timber will be extracted from a comparatively small area. This is not usually the case in Burma.

In most areas teak and hardwood extraction are usually carried out separately. There are several reasons.

Teak and hardwood extraction were carried out by different companies and traders before the teak extraction and sawmilling enterprises were nationalized. To avoid any confusion between the teak and hardwood operations, marking of hardwood selection felling was done seven years after or three years before girdling of teak, that is hardwood extraction was done seven years after or six years before teak extraction.

After nationalization of the teak industry in 1948 and when teak extraction was commenced by the former State Timber Board, hardwood extraction was carried out by private traders and extraction of teak and hardwood were therefore conveniently done separately. Working plans on the basis of separate extraction were thus prepared by the Forest Department for a long time.

The felling cycle for teak has not in general been coincident with that for hardwood since the hardwood operations have been carried out by the Timber Corporation, that is, since 1963, for on a silvicultural basis the felling cycles are not the same and it is not possible without loss of production to carry out teak and hardwood operations at the same time.

The Timber Corporation is trying to extract teak and hardwood from some areas at the same time. However there are some problems. Teak extraction areas cannot be fixed until the teak is girdled in preparation for extraction and this is not done until the prescribed yield is reached. If all hardwood was extracted from areas where teak is taken out, the volume of hardwood would be more than required to meet the targets. It is therefore only possible to extract teak and hardwoods together at the beginning of the planned periods. The volume of exploitable wood per hectare at any one time is therefore usually very small. This is one of the reasons for the lack of mechanised extraction in Burma.

The joint use of elephants and crawler tractors has been tried in Momeik Agency, Upper Burma. The elephants worked in the most difficult terrain and dragged the logs from the stumps to some point from where a tractor could prepare a snig trail and from which they snigged the logs to a floating stream. One problem in such joint use is that the elephants could not drag the long logs which would be preferable for machine skidding.

1.2.3 Water Transportation

1.2.3.1 Introduction

Every large stream in the forests of Burma has served as a transportation link down which dry teak logs have been floated to the main rivers. Dry teak logs are transported by floating in single logs in streams which are not fit for rafting. As soon as they reach a suitable river the logs are made up into rafts. Booms are usually built near the junction of a floating stream with a rafting river for the purpose of collecting the logs for rafting. The rafts are towed down the river to Rangoon.

In 1970-71, 82% of teak logs were transported by waterway, see also Section 1.1.7, page 28. Only a small percentage of hardwood logs are transported by river. As shown in Table 1.12, road and rail are the more important methods for transporting these logs.

Table 1.12 Hardwood transportation by road, rail and river 1970-71

Method	per cent
Road	60
Rail	22
River	18

1.2.3.2 Floating

Clearing of floating streams is necessary. It is usually done in the dry season before felling and snigging operations commence because debris can be burned and also carried away in the first stream rise of the wet season. In small streams blasting of projecting rocks may be necessary and also straightening of the stream by cutting sharp bends.

Log driving in the floating streams is necessary during the rainy season and these streams are patrolled with elephants to break any timber jams which have formed. Security measures are necessary for patrolling along the long stretches of streams which pass through insurgent activity areas. The patrols note the positions likely to hold up the logs such as narrow places, sharp bends and backwaters. Jams occur, usually at bends, if the logs are longer than the width of the stream and the logs are usually crosscut to ensure they are shorter than the width of the floating stream. In low bank sections of the streams the logs can drift out of the main stream and be left on the bank.

Depending on the frequency and intensity of the rains and the speed at which the river flows a proportion of the logs is not floated down to the main river in the one season. It is expected that only 30% to 50% of total logs in the streams will arrive at the main river during a rainy season (Table 1.8).

In some areas booms are built at suitable places in the main floating stream and the logs collected trucked to a railway siding or a main river for rafting. This is usually done to avoid floating the logs through areas notorious for theft.

In some areas, for instance Zigon and Tharrawaddy Agencies, the streams have no defined banks when they reach the plain areas and a special method for river training is used. Booms are built across the streams at defined banks and the logs are punted down to the rafting area with man control or they are trucked to railway sidings.

Transportation of timber by water is a cheap method but there are disadvantages. Green teak and hardwood logs do not float. Teak and hardwood species are associated together in the forest and where the harvesting operation is to remove not only dry teak but also green teak and some hardwood species, special arrangements must be made for the green teak and hardwood. They must be trucked to the river depot or sawmill.

Movement of logs depends on the intensity and frequency of rainfall to flood the streams. In low rainfall years, outturn logs that arrive at the main river may be very low resulting in short supply of wood.

There are some losses in the floating streams before arriving at main rivers. Sometimes booms are broken due to heavy floods and logs drift and are lost. The losses are shown in Table 1.8.

1.2.3.3 Rafting

Logs which arrive at the main rivers are made into rafts for further transport. At Prome rafting depot, on the Irrawaddy river, rafts are made in seven or eight sections, each consisting of 25-30 logs but depending on the size of the logs. A raft of 200 logs or about 300 m^3 is prepared by the labourers. Six rafts containing about 1200 logs or about 1800 m^3 are towed down the river by launch to Rangoon. Each raft is managed by a crew of 3 or 4 men who live in a small hut on the raft. Plates 5 and 6 show rafts on the Irrawaddy river.

To manage a raft four men are employed in the rainy season and three in the dry season. Rafting is done all the year round by contract labour. Charges for making the logs into a raft are about $A25 (Ks.200/-) and managing charges on the way to Rangoon are about $A80 (Ks.650/-) in the rainy season and about $A60 (Ks.500/-) in the dry season. Fees for towing by launch are about 40 cents (Ks. 3/25) per log. The distance from Prome to Rangoon is about 390 km (240 miles) and it takes about 15 days in the rainy season and 20 days in the dry season. If there is no loss on the way about $A12 (Ks.100/-) is paid to the crews as a bonus.

Green teak may be rafted with dry teak logs. Two or three green teak logs are placed alongside each dry log in a parallel position to form a section.

Plate 5: Rafts on the Irrawaddy river.

Plate 6 : Rafts on the Irrawaddy river.

Non-floatable timbers such as pyinkado (*Xylia dolabriformis*,Benth), in (*Dipterocarpus tuberculatus*, Roxb.) are also rafted with the aid of bamboos or very light timbers such as baing (*Tetrameles nudiflora*, R.Br.) or letpan (*Salmalia malabaricum, D.P.*). Wooden boats and empty drums are also used in the rafting of non-flotable timbers.

The bamboos are first tied into bundles. Each bundle consists of 100 culms if the species is tinwa (*Cephalostachyum pergracile*) but where the species are kyathaungwa (*Bambusa polymorpha*, Mumno.) or wapyu (*Dendrocalamus membranaceus*, Mumno.) only 50 culms are used in a bundle. When using light timber as floats, five hardwood logs require seven large logs of baing - (*Tetrameles nudiflora*, R.Br.) as floats, and a bundle of bamboos is often attached to the sides of each section to make the raft more buoyant.

The bamboos and light timbers used in a mixed raft, that is with hard-woods, can be sold or utilized at the destination of hardwoods but boats and empty drums must be brought back and used again and this always presents difficulties.

Logs cannot be transported upstream in this manner, as the fastenings break with the resistance of the water, and the use of this method of floating is therefore very limited.

1.2.4 Truck Transportation

Trucks are required for the transport of wood and also the labour and materials used in forest operations. In Burma there are about 2000 trucks used in timber transportation.

Most of the existing trucks are capable of carrying loads of up to 6 metric tons (Plate 7). In the forest these trucks are loaded to less than their capacity due to the low standard of forest roads. Many Hino trucks are owned by the Timber Corporation. They are two-axle or six-wheel trucks without four wheel drive or even a winch to get them out of bad places. At present, more than 50% of the mechanical equipment owned by the Timber Corporation is out of action due to age, poor maintenance and lack of appropriate spares (Anon. 1974).

Hino trucks are medium size trucks without trailer or semitrailer and the maximum length of the log carried on them is limited to about 7 m (23'). Longer logs are loaded on to other trucks with semitrailers. The Timber Corporation owns only about 130 heavy trucks with twin axle trailers capable of carrying loads of 25 metric tons.

Privately owned trucks are often four-wheel drive but they are usually very old and most of them relics of World War II. The number of private trucks is decreasing year by year due to lack of spare parts (Table 1.13).

Table 1.13 Timber transportation capacity, trucks

Particulars	1964-5	1970-1	1972-3	1974-5	1975-6	1976-7
Public	-	602	1009	1134	1438	1607
Private	-	1000	767	994	604	463
Total	1613	1602	1776	2128	2042	2070

Plate 7: Two axle log truck with one log.

Haulage over low standard forest roads and the low rates paid for trucking are also causes of the decreasing number of trucks. As it is not easy to get spares, owners prefer to use their trucks on better roads.

Trucking of timber in the forest can only be done in the dry season, that is from January through the middle of May. As a consequence haulage is usually done in two stages. In the dry season, logs are trucked out from the forest along feeder and access roads to sawmills, rafting depots and all-weather roadhead depots, to build up wet weather stock. In the wet season logs are hauled from the all-weather roadhead depots to mills or rafting depots.

A road network which can be used by trucks is of course very necessary for transport. The actual value of a forest depends largely on its accessibility and for example a forest which is nearer to a public road is more valuable because timber from that area can be removed at lower cost, and non-floatable hardwoods have no market value until they are made accessible by roads because they cannot be transported by waterway. The value of standing wood thus depends on its distance from a public highway or railway and the characteristics of the road by which the wood can be extracted.

The following four classes of forest roads were built by the Forest Department when logging and transportation of timber was done by private firms and small traders.

Main roads

These roads are usually metalled and connect the forest to a public highway or to a railhead. As they are used throughout the year they must be well drained. Main roads are also used for transport of agricultural produce by local villagers with their carts. The rims of cart wheels are small and they may damage the surface of roads very seriously thus increasing construction and maintenance costs.

The width of metalling is about 3.5 metres and the width of the road is about 4.5 m to 6 m.

Forest cart roads

These were intended for the extraction of timber and act as feeder roads to the main roads. They are usually earth roads about 3.5 m in width and can only be used in dry weather. They are not suitable for motor trucks.

Bridle paths

These tracks are not designed for timber extraction but to provide quick and direct routes from place to place. They are chiefly used by baggage elephants and avoid damaging the surface of cart roads during the rainy season. The width of track is about 1.8 m and it is sometimes called an 'elephant path'.

Inspection path

These are narrow tracks about one metre wide, just sufficient to enable a man to pass easily.

Temporary roads were occasionally constructed by the Forest Department to assist timber traders in the extraction of timber from near the felling site to the existing roads but more often such access was provided by the contractors working in the area. These road construction works were abandoned after hardwood logging operations had been carried out.

The Timber Corporation now prepares seasonal forest roads with bulldozers for the transportation of timber. They are for dry season use only. Road construction usually starts in about November when the monsoon rains stop, but in Lower Burma where the rainfall is heavy, it may not be until December. These seasonal roads have no standard specification with respect to for example width, gradient, radius of curvature and design speed.

As the roads are used only in the dry season most of the road alignments can be most economically chosen along the watercourses. It is not necessary to build expensive stream crossings for these temporary forest roads for, excepting large and deep streams, most watercourses are dry or nearly dry during the trucking period and the banks of each side of crossings are graded down to form earth ramps. The easiest construction route is taken, often following along dry stream beds. The road surface at sandy places along the stream beds are improved by laying bamboo matting along the wheel tracks.

The standard of construction can be epitomised by examples of construction practice. If water is still running in the stream a hollow log is sometimes used as a culvert to allow the water to continue flowing at a crossing. In soft spots poles are laid down across the road bed and kept in place by longer and heavier logs at both ends.

In the hilly areas bulldozers are used in road construction but there is no detailed planning for the construction of the roads. The surface is not gravelled and compaction is generally left to the traffic.

Road maintenance is nearly always done by manual labour during the trucking season. Four to five men are employed for 15 to 20 km of road. They use native hoes to fill the depressions on the wheel tracks. It is only in a very few areas that graders are used to shape the road surface. The roads are not maintained after harvesting is over.

The road standards are such that only a relatively low volume of wood can be loaded on to the trucks hauling along them.

1.2.5 Rail Transportation

The use of light railways in the forest for timber extraction and transportation is very rare in Burma. There are two reasons. In most areas the country is too hilly or broken for railway construction, and the widely scattered fellings under the selection system results in a low marketable timber per unit area.

The first attempt to make use of tramways by the Forest Department for the working of teak in Burma was in 1912, in Zigon Division, and for several years a tramway was worked with a fair amount of success (Lloyd, 1929). The experiment afterwards proved to be a failure for teak extraction, and tramways have not been used since by the Forest Department.

In Pyinmana Forest Division, a narrow gauge railway was constructed by a timber company and it was used to transport the wood from the forest to the sawmill. The logs were dragged by draught animals from the stump site to the forest railway and then sent to the sawmills.

In some areas like Pyinmana and Toungoo, logs are transported by truck from the forest to railway stations and sent to Rangoon by public railway. A railway line from Pyinmana to Taungtwingyi, passing through the forests, is very useful for the transport of timber from that area. There is no road from Mandalay to Myitkyina, Upper Burma and the railway line is used for the transport of timber. Seasonal forest roads are constructed in these areas and logs at the landings are hauled by trucks to the railway stations and then transported by the railway to Mandalay and Rangoon.

There are some advantages in the transportation of timber by rail. Any kind of wood can be readily carried whereas with water transportation special arrangements must be made for non-floating logs. Wood can also be carried all the year round relatively independently of seasonal conditions. There are also some disadvantages. Sufficient wagons cannot be made available and there is a shortage of locomotives. Because of irregular supply of wagons to the sidings the labour for loading may not be readily available and demurrage costs may be incurred.

1.2.6 Loading

The efficiency of a log transport system depends of course to some extent on the loading method. For example, productivity can be improved by reducing waiting time for the loading and unloading operations. In general two methods, manual and mechanical, are used in Burma.

1.2.6.1 Manual loading

Manual or hand loading is still used in those parts of Burma, for example, Thayet Agency, where the size of the logs is small and mechanical loading is not available or is insufficient. It can be an economical system because there is no capital investment and labour is relatively cheap but the rate of loading is very slow. The logs are stacked parallel to the road and two skids about 3.5 m long are placed 3.0 m apart parallel to each other from ground level up to each bolster of the truck with a minimum slope of 1:2. The loading skids must be dug well into the ground to prevent them from slipping off. Seven or eight men roll each log up on the skids and to the truck. The procedure is dangerous. In some areas, a loading ditch is dug by a dozer so that when the trucks drive in the ditch the tray is at ground level and the log can be rolled across.

Manpower with the simple mechanical assistance of a pulley block is also used in loading. Each log is lifted so that a truck can back under the log which is then lowered on to the truck.

1.2.6.2 Loading by means of mechanical power

There are many machines that would be suitable for log loading in Burma. Self-loading trucks, independent loaders and front end loaders are all used but some to a very limited extent.

Self-loading trucks

They can load and unload themselves if necessary and the loader is always available. The logs should be stacked in a truck load to avoid loss of time in travelling between stacks. However, the loading system is very flexible and appropriate for relatively small log dumps.

Independent loaders

These are usually a 4 x 4 truck with a winch drum and frame mounted on the platform. They are suitable only for loading and for effective utilization must serve a number of log trucks each of which hauls a full load. They are not necessarily restricted in design, construction and size by the requirement that they have a special prime mover and the winch may be mounted on a standard truck and driven by the truck engine through the transmission. This is a common machine in Burma.

A frame can be set up at an angle of 30 or 40°, higher at the rear end of the truck platform. A winch drum is mounted at the front end of the platform and a cable from it, which passes through a pulley at the higher end of the frame, can be attached to the log as near as possible to the centre of its weight; to keep it in a horizontal position. When the winch is driven the cable is reeled in and the log is dragged towards the loader truck, lifted up to the frame which is high enough for a truck to back under the log which is lowered down on to the truck by releasing the winch. The machines are quite productive and are able to load the largest logs. There must of course be sufficient space at the landings for both truck and loader.

Front end loaders

Front end loaders are very efficient machines for loading timber. They are mounted on either large heavy duty tyres or on tracks.

Wheeled type loaders should preferably have articulated frame steering and drive to all wheels to enhance their manoeuvrability, otherwise loading can be very slow, particularly in small landing areas. Wheeled type loaders can be moved rapidly from one place to another.

Tracked type loaders should be used at landings at which a large number of logs can be stockpiled. They can load as quickly as, or faster than, wheeled loaders especially in the small landing areas. Tracked type loaders move only slowly from one landing to another and where large travel distances are involved in a shift of the machine a wheeled loader should be used.

1.3 DEVELOPMENT OF THE WOOD TRANSPORTATION SYSTEM

1.3.1 Introduction

On a number of occasions the existing transportation system has not been adequate to enable the Timber Corporation to meet contracts for the delivery of wood. For example, in 1969 to 1971 wood available in the forest to meet the contracts did not reach the mills or ports. The sale of wood is an important source of foreign exchange and the Government is endeavouring to increase foreign exchange earnings from the sale of wood. There are thus two reasons for development of the wood transportation system; to ensure that existing contracts are met and to enable increased sales to be negotiated.

It must be accepted that by the standard of mechanized extraction practised in developed countries the existing wood transportation methods in Burma are primitive. It has already been noted that in terms of sustained yield of teak and hardwood there is scope for increased production. There can be little doubt therefore that mechanized skidding accompanied by improvement to the haulage system could increase the rate of delivery of wood from the forest to the mill or port. However, this is only one option and fraught with difficulties, for procurement of imported goods often presents insuperable obstacles. Many machines are already idle because of lack of parts.

In detail and without constraints of foreign exchange and technical capability there are many options that could be examined in determining the most appropriate way to improve the wood transportation system that is now in operation.

In this section the more general options are canvassed as background to the methods adopted, and presented later, to review the existing transportation system in relation to the advantages and disadvantages of improving the forest road system to enable an increased rate of log production.

1.3.2 General Appraisal of Extraction Equipment Options

The extraction of logs in Burma has not been increasing significantly year by year and one reason advanced is that there is insufficient power. Elephants are mainly used but the number decreased since World War II from 6,500 to about 3,500 at present.

Mechanization depends on such factors as availability of capital, credit facilities, training of managers and operators, service and backup facilities. The availability and productivity of labour in forest harvesting operations, its skill, experience, motivation and cost are also critical features for lack of labour can be a pressing reason for mechanization and at the same time lack of skilled labour may prevent effective use of mechanized equipment. In most of the countries with advanced technology competition for skilled labour, increasing cost of labour and improved machines have resulted in cost advantages from capital investment in machine technology. The most obvious machine technology for use in forest harvesting in Burma is discussed below. Cable hauling is considered to be inappropriate for the following reasons.

Cable hauling is most appropriate for clearfelling on steep ground where yields are high. Clearfelling is not practised in Burma and its introduction presents many difficulties with the existing markets. For example, at present teak and hardwood are usually removed at separate times because of the relative yields and market demands. The removal of teak and hardwood at the same time has been tried but as discussed in Section 1.2.1 there are many constraints precluding general adoption of this policy. Modification of the silviculture system to enable more intensive harvesting operations, such as clearfelling, would, from a national point of view, require a market change in the demand for wood. While this may be a possibility it is not seen as an option in terms of this study. Thus it is unlikely that cable hauling systems will be introduced extensively in the near future. Nevertheless it is noted that there could be considerable advantage in the joint extraction of teak and hardwood whenever this is possible and supplying the remainder of the market from separate operations for each type of wood.

1.3.2.1 Rubber-tyred skidders

Rubber-tyred skidders usually have frame steering and the front and rear portions can articulate about each other. Four-wheel drive and a short turning radius enables them to manoeuvre around obstacles and at the stump. A light bulldozer type equipped with a blade is useful for construction and grading skid trails, clearing landing sites and decking logs at the dump. The skidders are best adapted to tree length and multi-log length systems and they have advantages of mobility and speed, particularly when operating on bulldozed skid tracks.

In general rubber-tyred skidders are not as versatile as crawler tractors which can be used for road building and over a greater range of slopes. Snigging uphill and downhill they may be operated on slopes from 0 to 15^{o}. Snigging downhill they would normally operate on slopes from 0 to 15^{o} but up to 20^{o} is feasible. The use of rubber-tyred skidders would be feasible on much of the terrain now logged in Burma.

1.3.2.2 Crawler tractors

Heavy duty crawler tractors can work efficiently on slopes up to 25^{o} and they can cut tracks for working on steeper slopes. The crawler tractor, equipped with bulldozer blade and towing winch may therefore be an effective compromise in choosing equipment for logging. They not only snig the logs but can bulldoze the roads and snig tracks. They can also be used in the preparation of landings and loading ramps.

Tractors and skidders with integral arches have several advantages compared with ground snigging. An integral arch is basically an 'A' frame, bolted to the back of the tractor with a fairlead near and a little to the rear of the winch. The logs are brought to the arch by the tractor winch and the front end is raised to the horizontal roller. The lift to the front end of the log during snigging reduces frictional resistance and the risk of 'dragging in'. Greater loads and hauling speeds are thus possible. The main disadvantages of integral arches are their weight and reduction in manoeuvrability.

Many of the crawler tractors now used in the logging operations in Burma do not have integral arches and it seems advisable to investigate the possibility of ensuring that in the future crawler tractors be equipped with these arches for the snigging distances are relatively long.

1.3.2.3 Trailing arches

Another type of tractor attachment is the trailing arch which is well adapted to selection logging and even better adapted to clearfelling. By using a trailing arch production can be increased and unit cost of production decreased. It enables tractors to haul larger logs in the extraction phase. However in difficult terrain the bulldozing capacity may be more important than the snigging, in which case the bigger tractor may be more efficient. A trailing arch is expensive, heavy and it absorbs a good deal of the tractor's pulling power, especially for uphill snigging. They are most advantageous when skidding distances are relatively long and log sizes are large. This is now the case in Burma and it may be that trailing arches could be used to collect logs from transition dumps to landings by hauling over relatively long distances and avoiding truck haulage from deep within the forest.

1.3.2.4 Forwarders

There are a number of different models of forwarders most of which have frame steering and drive to all wheels. These can work in relatively poor ground conditions and on slopes up to 15^{o} for downhill hauls. Forwarders are usually equipped with a knuckleboom loader and load themselves or other trucks. They are forest vehicles which require a skilful operator. They are not able to readily work a multilog length or tree length system and they are sensitive to the effect of yield per hectare. This machine is unlikely to be generally suitable for extraction of logs in Burma where yields per hectare are very low and most forest areas are steeper than 15^{o} slope.

1.3.2.5 Combination of crawler tractor and wheeled skidder

Combined use in a compartment or adjacent compartments of crawler tractors and wheeled skidders may be more effective than separate use. There are certain basic differences between the two types of machine that make them more or less well suited for different conditions of work but which often apply within each compartment. The crawler is expensive, powerful and travels with a limited speed whereas the wheeled skidder is cheaper, travels faster but has less traction than the tractor. In crawler snigging the tractor pushes its way through the remaining stand to every felled tree. It would also construct a simple road between the landing and the tree. However the snigging phase of the operation could be taken over by the wheeled skidder, the wheeled skidder operating on prepared trails in transporting the logs to the landing while the crawler could operate in the upper part of the transport system bringing logs from the stump in steeper sites to the prepared trails. With this organization, the crawler can make use of its power and the wheeled skidder of its speed. The use of crawler tractor and wheeled skidder in combination may mean lower cost and less truck roads. The combined use of these machines might be useful in logging operations in Burma but the low production volumes per hectare with the separate production of teak and hardwood may preclude trials with the system.

1.3.2.6 Combined use of skidder and elephant

The elephant is one of the main extraction powers used in logging operations in Burma though its load capacity is not impressive. The elephant can be used in snigging in the very difficult areas where skidders cannot work efficiently.

In the hilly areas where the terrain is so steep that the skidder would not work efficiently, elephants could be used to push down the logs and the skidders to snig the logs to the roads or landings. Trail preparation to each tree is not needed with elephants and this saves time and cost for when the felled trees are scattered it may not be economic to make snigging trails to individual trees. The elephants could be used to collect the logs, dragging them from the scattered stumps to a certain point and a skidder could then snig them to the landings. One problem with joint use would be that the productivity of elephants is small while that of a skidder would be high.

1.3.2.7 Combined use of crawler tractors and elephants

Combined use of crawler tractors and elephants was practised in Momeik Agency, Upper Burma. The elephants dragged the logs from the difficult areas to the sites where the crawler tractors took over. One problem is that the most appropriate log length is different for crawler tractors and elephants.

1.3.3 General Appraisal of Road Haulage Options

There may be advantages if a greater proportion of the transportation of wood from landings to mills or depots was by trucks as compared to water transportation. This may also apply to the transport of dry teak, which is traditionally by floating in streams from the forest to the river. There are quite high losses of dry teak in floating and girdling of trees three years before felling is, while necessary with present practice, a wasteful method because of loss of increment.

The costs of truck haulage depends of course on the road standards but they are also determined by the size and kind of truck, the volume of timber to be transported and the duration of the operation. Obviously, the greater the volume of timber to be hauled and the longer the period of anticipated use, the better the road that should be built and it would not be appropriate to use trucks which are capable of carrying only small loads on very high standard forest roads suitable for big trucks with large volumes of timber.

1.3.3.1 Trucks

Trucking is a widely used method in developed countries for transporting forest products from the harvesting area to the mill or market for their manoeuvrability, improved load carrying capacity, increased power and transmission flexibility have promoted the greater use of trucks in all logging regions of the world. A wide range of trucks, tractors and trailers are available and it is necessary to select the equipment best suited to a given situation. Both petrol and diesel trucks are used but diesel is the most common.

The effectiveness of any truck haul operation is dependent on the road network and the standards adopted for its construction and maintenance (Wackerman,1949). Wackerman suggests that carrying wood on a truck presents the cheapest land transport cost per unit volume per kilometre, even over roads built to a low standard. For example, an extra 2 to 3 kms on a truck haul may not appreciably increase the total hauling cost, whereas a similar increase in skidding distance would be prohibitively costly.

1.3.3.2 Types of trucks

In many logging operations it has been a common practice to use relatively cheap mass-produced trucks never designed or intended for logging, but there are now many trucks designed and engineered specially for log hauling which have the combination of strength and power necessary to carry maximum permitted payloads with much less risk of failure. Such trucks may cost two or three times more than the mass-produced ones for general highway hauling but deteriorate much less rapidly and with good preventative maintenance can give a lower unit cost of hauling.

There are many log truck configurations. McNally (1975) suggests that combination rigs can be classified as semitrailer, full trailer and pup trailer. A semitrailer is one with the axle, either in single or tandem form, located near the rear end of the trailer. A full trailer is one with axles, either in single or tandem form, placed near the front and the rear end respectively of the trailer. A pup trailer is one with the axle, either in single or tandem form, placed near the centre of the trailer. The number of axles for each combination can be selected on the basis of the hauling operation. Rigid trucks are usually classified in terms of the number of axles. The configurations illustrated in Appendix 1.4 show typical vehicles and the statutory load limits for the Australian States and Territories at November 1977.

In general the most economical size of transport vehicles is dependent on the length of haul and the loading and unloading methods used (Anon. 1974). Usually it is found that the longer the haul the larger the optimum vehicle. However, the relationship is rather insensitive and requires specific analysis in each case. On short hauls, loading becomes a major element of round-trip time and, with very large vehicles in particular, too great a portion of the cycle time may be spent in loading and unloading, waiting on other trucks and other delays. Again, on very short hauls, a greater portion of the haul is likely to be on roads with steep grades, sharp curves and narrow width than on large hauls on main roads.

Trucks with a capacity of 3 tons proved to be quite suitable and efficient for short hauls on low class roads and slow loading in West Africa (Cermak and Lloyd, 1962). On the other hand the world trend in log trucks has been to increasing load carrying capacity.

1.3.3.3 Truck engines

There is no ready made rule that can be applied to making a decision whether to select a petrol or a diesel engine. Each application must be considered on its merits. The overriding criterion is economy of owning and operating the vehicle. The diesel is a more efficient engine and burns a fuel that costs approximately the same as petrol yet has more joules per litre and therefore the rate of fuel consumption is less for the same power. In an operation where engines idle for much of the time the diesel has the advantage that it idles on about half the fuel volume used by petrol engines. The diesel engine is also more durable and thus has lower maintenance costs and higher availability (McNally, 1975).

Diesel engines cost more than petrol engines because they must be heavier and more ruggedly built due to the higher compression ratios and higher sustained combustion pressures. The diesel powered truck also costs more because heavier drive train components are necessary to withstand the higher engine torques and because greater cooling capacity is needed to offset the greater heat built up in the engine.

If the purchase cost differential between petrol and diesel engines can be paid for through savings in fuel costs and maintenance expense within a reasonable time, the diesel could be the better investment.

There is not unanimity of opinion within the forest industry with respect to the comparative life in kilometres or hours of present day petrol and diesel trucks working under the same conditions. McNally (1975) estimated that the life of diesel-powered trucks is the greater by 50-100%. Thus, if a diesel truck costs 50% more than a petrol truck and lasts two-thirds (67%) longer, for example 5 vs. 3 years, depreciation combined with interest will be approximately equal for the two trucks.

McNally (1975) examined data obtained in North America in the 1960s for a comparison of petrol and diesel engines. At that time and for 80,000 kilometres of travel per year, with trucks of 190 Kw engine power there was an annual saving of $1850 in favour of a diesel-powered truck. McNally (1975) suggested that the savings could be greater with more powerful engines which could be required for heavier loads, higher speeds and lower hauling costs.

Engine power requirement, given a specific road, is a function of gross vehicle weight, frontal area and road speed (McNally, 1975). It must be great enough to overcome rolling resistance, grade resistance, air resistance and chassis friction resistance. Altitude must also be considered since petrol and naturally aspirated diesel engines lose power at the rate of 10% for each increase of 100 metres in altitude (McNally, 1975). But a naturally aspirated diesel engine will improve its operation at high altitude by restricting the amount of fuel injected into the engine cylinders.

1.3.4 General Appraisal of Loading Options

Loading and unloading have a direct influence on hauling productivity. Mechanized loaders could be used for all loading and unloading operations.

Currently in Burma the loaders available are used only for loading and manual labour is always used for unloading. The choice of the loading method and equipment in relation to the volume or weight of timber to be removed is an important aspect of a transportation system. Speed of loading is also important. If the loading capacity is lower than that of hauling then the trucks may lose time in waiting. When loading capacity is greater than hauling capacity, then the loader is idle until an empty truck arrives.

In areas where the volume of timber handled at each landing is small then mobility of loading equipment is essential. Such mobility can be attained by using wheeled loaders rather than a crawler type. Loading and unloading times should have little influence on the number of trips per day on the longer hauls but excessive loading time may reduce the number of trips per day on short hauls (Cermak and Lloyd, 1962). Loading time for a truck is determined *inter alia* by the size of log. The number of larger logs will be less than that of smaller for a given truck capacity. The time of loading will be shorter for larger logs if the loader picks up one log at a time.

The size of the log is a particularly important factor in Burma for the size of log extracted is influenced by the capacity of extraction power and terrain conditions. In the extraction of wood in Burma elephants and buffaloes are used. A pair of buffaloes can drag about 1 m^3 of log and an elephant can work about 4 m^3. To produce larger logs, machines would be required.

1.3.5 General Appraisal of Forest Roading Options

To substantially improve the standard of forest roads in Burma machines for road construction would be advantageous. Manual labour to build a high standard road for large trucks carrying large volumes of wood would be high and probably not available in the forest. Bulldozers equipped with a ripper attachment and motor grader seem preferable for high standard road construction. Earthwork movement could be done by conventional bulldozing techniques and a motor grader would carry out final shaping and maintenance work.

While the choice between the use of manual and animal power and the use of mechanical equipment is a fundamental one in relation to the provision of a forest road system in Burma, as it is in the provision of an extraction system, there are also of course other planning and design aspects of a road access system which present options for determination. For example, the intensity of the road network to be provided in a forest and the standard of construction of the roads at all sections of the network.

The intensity of a road network system should be related *inter alia* to the snigging distances and costs while the standards of construction should be related, *inter alia*, to the volume of traffic and the haulage costs along the roads. The balance between snigging costs, road construction costs and road haulage costs is a major question for determination by this study and analytic approaches to the planning and design of forest roads are discussed in Chapter 2.

CHAPTER 2

ANALYTIC APPROACHES TO THE PLANNING AND DESIGN OF FOREST ROADS

2.1 INTRODUCTION

In practice there are many procedures for the planning and design of forest roads. Many have, as their basis, policies and guidelines for the selection of geometric standards. For example, 'this manual seeks to provide guidelines which will help the forest manager to select the proper road standard and density or spacing and the logging system which will help to produce the lowest overall delivered wood cost' (FAO, 1977). Johnston *et al.* (1963) described 'drillbook guides' and 'ready reckoners' for optimizing the investment in roads. The guidelines adopted by many forest agencies usually have much practical experience of road construction and maintenance to support the suggested practices.

On the other hand there are analytical approaches to forest road planning. These approaches are reviewed in this Chapter. The purpose of the review is to determine their usefulness in analyzing the efficiency of some of the existing transportation networks in Burma, for analytical procedures have the compelling advantages that they reduce the dependence of decisions on judgment and experience. They do not appear to be widely adopted in forest road planning and design nor have they been adopted for evaluations of the efficiency of performance of existing forest road networks.

2.2 ANALYTICAL PROCEDURES FOR FOREST ROAD PLANNING AND DESIGN

2.2.1 Literature Review

Matthews (1942) used the breakeven point concept to develop procedures for determining the spacing and the standard of forest roads that would provide for extraction and road haulage of the wood at the minimum cost per unit volume. Solutions to the following classes of problems were presented.

- economic direct skidding
- road spacing formula
- road and landing spacing
- determination of road standards
- selection of haulage equipment
- selection of equipment and road spacing on slopes

Application of the procedures requires the following information.

- the volume per unit area to be removed
- the cost of road construction and maintenance
- the cost of skidding per unit distance
- the fixed cost of skidding for each trip
- the cost of road haulage per unit distance.

The main theoretical deficiencies in the procedures developed by Matthews (*op.cit.*) are that road standards and road spacings are not optimized together and that no allowance is made for the timing of expenditure on the roads, the cost incurred in transportation along the roads and the cash receipts from timber sales. However the use of present worth values obtained by discounting monetary values to a value at one selected time and the use of cut and trial procedures make the methods more acceptable and applicable. Matthews, page 20 (*op.cit.*) used cut and trial procedures in, for example, the selection of pre-hauling equipment and road standards and road spacing.

There are practical limitations to the application of the Matthews' methods.

The reliability of the results produced is of course dependent on the accuracy with which the required information is known and accurate unit cost data is not always readily available. Matthews (*op.cit.*) stated in 1942 'this limitation of accurate cost prediction may not be serious in industries in which the environment of production changes little from month to month in year to year. In the logging industry, however, identical production situations are the exception rather than the rule and unless the data of cost are broken down, recorded as unit costs, and correlated with the factors that control their values, they remain merely data of absolute cost and are of little use in deciding between alternative procedures'.

Reliable results are also dependent on accurate classification of cost into 'fixed' and 'variable' costs, that is respectively those costs that are fixed in aggregate amount and the unit cost of production varies with output and those that are fixed per unit of production and vary in aggregate amount with output.

The importance of this classification of costs into fixed and variable costs and the concept of the break even point, with particular reference to Matthews' methods is illustrated in Figure 2.1. It should be noted that the cost of skidding is increasing at an arithmetical rate and the road construction cost as the reciprocal of the same changing value and in such cases the minimum cost is achieved when the variable costs of skidding and the road construction costs are equal. This occurs at an average skidding distance of about 1800 metres in Figure 2.1.

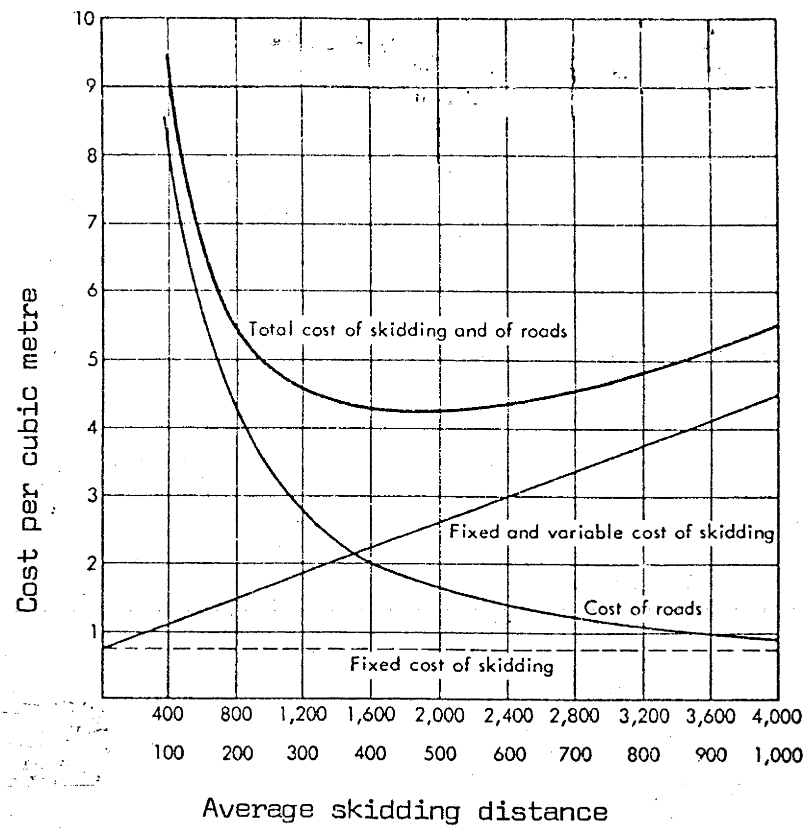


Fig. 2.1 Relationship between roading and skidding costs per cubic metre

Figure 2.1 also illustrates the difficulties that arise when formulae are used to solve break even analysis problems. The break even point can be readily determined by simply calculating the road spacing at which road construction costs per unit volume are equal to variable skidding cost per unit volume. However the formula for the relations shown in Figure 2.1 may be quite complex.

As presented by Matthews (*op.cit.*) road construction costs per unit length remain constant. That is they are dependent on say topography rather than traffic volumes. However, road construction costs should be related to the cost of road transportation. Matthews (*op.cit.*) is contradictory on this point. In developing road spacing formula as a criterion of the economic direct skidding distance he states 'the cost of hauling on roads if they are to be used was ignored. If timber is being ground skidded to roads the cost of skidding will be so much greater than that of hauling on roads that the hauling cost may be safely ignored', Matthews, page 126 (*op.cit.*). In developing procedures for determining the economic service standard for roads he states 'the service standard of any hauling road may be progressively improved as long as such improvement includes a reduction in cost of hauling on that road that is greater than the cost of improvement ..... the point of minimum cost is approached as total hauling cost and road construction costs are brought into balance. The principle that minimum cost for road construction and haulage cost on roads is obtained when these two costs are approximately equal is theoretically true for all situations but can be practically applied only to those in which there is considerable measure of flexibility in cost of construction as opposed to cost of hauling', Matthews pages 162,163 (*op. cit.*)

It is concluded and at issue with Matthews that the cost of road hauling should not be ignored in determining road spacing as a criterion for economic direct skidding distance.

Matthews' statement, quoted above, 'that the principle that minimum cost for road construction and hauling cost on roads is obtained when these two costs are approximately equal, and is theoretically true for all situations' is also questioned and is taken up later in this review.

The theoretical difficulties associated with the methods presented by Matthews (*op.cit.*) can be illustrated in a mathematical way by adapting an analysis presented by Larsson (1959).

The total cost of loading and unloading in the forest area, transportation in the forest area, loading and unloading from motor trucks, transportation on the road as well as road construction and road maintenance expressed as costs per cubic metre of wood can be written for the schematic layout shown in Figure 2.2, as follows.

$$K_w = t_f + \frac{a}{2}. \; t_r + L + \frac{b}{2}. \; z + \frac{y}{2.p.a.} \qquad (1)$$

where K_w = Total cost of extraction and haulage from stump to forest road boundary

t_f = costs; per cubic metre, of loading and unloading in the forest area, which are independent of the road spacing

t_r = costs; per cubic metre per unit distance of transportation in the forest area, which vary with road spacing

L = cost per cubic metre of loading on and unloading from motor trucks

z = cost, per cubic metre per unit length, of road transportation

y = cost of road construction and maintenance for unit length

p = average production in cubic metres per unit area

a = the range of roads (i.e. half the distance between the roads)

b = length of the road.

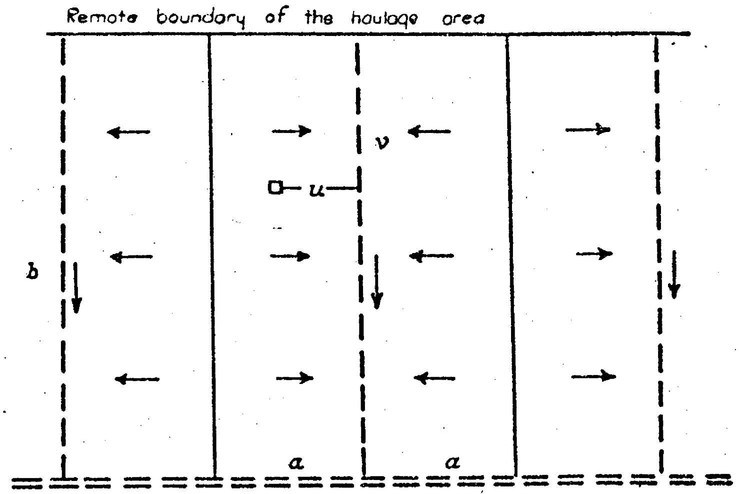


Fig. 2.2 Schematic layout of a road system in which the logs are pre-hauled direct to the motor truck haul roads

If the cost per cubic metre of transportation on the road (z) and the cost of road construction per unit length (y) are each independent of the road spacing (a) then Equation (1) can be differentiated with respect to (a) to determine the road spacing that could give a minimum total cost per cubic metre.

Thus K_w is a minimum when $\frac{dK_w}{da} = 0$

$$\text{now} \quad \frac{dK_w}{da} = \frac{t_r}{2} - \frac{y}{2pa^2}$$

and K_w is a minimum when

$$a = \sqrt{\frac{y}{p.t_r}} \qquad (2)$$

The condition determined by Equation (2) corresponds with the break even analysis procedures presented by Matthews (*op.cit.*) for when the road spacing (a) is determined by Equation (2) the total cost of the variable component of snigging per cubic metre is $\frac{a}{2}. t_r$ and the total cost of the roads per unit length (y) is $a^2.p.t_r$, that is, $\frac{a}{2}.t_r$ per cubic metre per unit length since unit length of road serves a total production of p.2a cubic metres.

Equation (2) also forms the basis for other approaches to the problem of determining road spacing, for example, Silversides (1949), Steinlin (1963), Strehlke (1963), Sunberg (1976).

However, as noted in the review of the methods adopted by Matthews, the unit cost of transport along roads will depend on the road standard which should depend on the timber volume to be hauled along the road and which in turn is dependent on the spacing 'a' in the schematic diagram, Figure 2.2. That is, 'y' and 'z' in Equation (1) are not independent of the road spacing and differentiation with respect to 'a' is not valid.

Larsson (*op.cit.*), page 13 derives an expression for the total cost of wood transport within the forest which assumes that the cost of transportation and loading and unloading in the forest is dependent on the snigging distance, that the road standard is a quantity which is dependent on the volume of timber transported and that the cost of transportation on the road is dependent on the road standard. Larsson (*op.cit.*) notes that, in addition to the condition that the total cost will be a minimum when the first differential of the expression for the total cost with respect to the spacing 'a' (see Figure 2.2) is zero, 'if the most economical road standard has been reached then a further road improvement which involves an additional cost shall not yield any profit and this additional cost shall be equal to that reduction in the cost of transportation which results from the improvement'. The mathematical formulations presented by Larsson (*op. cit.*) are given in Appendix 2.1.

The practical application of the rigorous mathematical approach formulated by Larsson (*op.cit.*) for the model schematically represented in Figure 2.2 requires mathematical description of the relation between the cost of transportation in the forest area and the skidding distance and the relation between the road standard and the cost of transportation on the road.

Larsson (*op.cit.*) page 27 assumed that the variable cost of transportation in the forest, including the movement of people, varied directly with distance. The assumption was made on the basis of time and motion studies.

Larsson (*op.cit.*) also assumed, on the basis of interviews and questionnaires, relations between road standard and the cost of transportation. In a subsequent work Larsson and Rydstern (1968) updated and revised the relations assumed by Larsson (*op.cit.*) and the revised relations are given in generalized form in Tables 2.1 and 2.2 and in Figure 2.3.

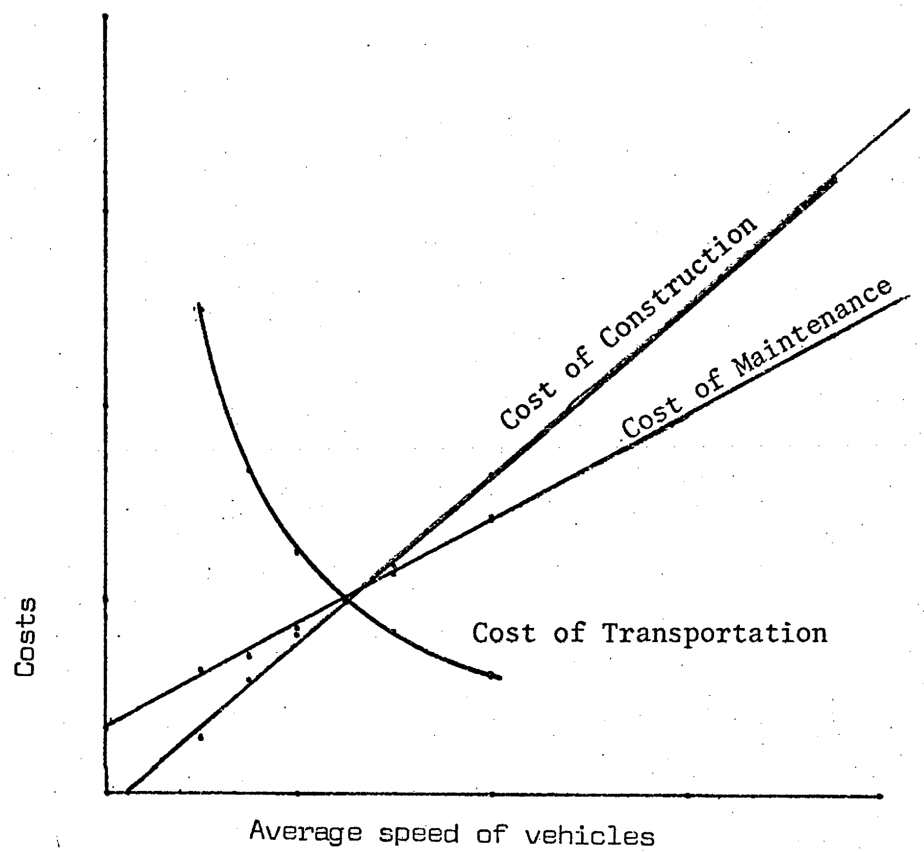


Fig. 2.3 Relationship between road standard and the cost of transportation

Based upon the theoretical formulation and the empirically based assumptions Larsson (*op.cit.*) presented diagrams representing the relations between the average production 'p', the length of road 'b' and the range of the road. The diagrams were revised in Larsson and Rydstern (*op.cit.*) and the revised diagrams are given in Appendix 2.2 and are referred to later.

Larsson (*op.cit.*) used the results which have been summarized to investigate a system of 'primary and secondary motor truck haul roads'

Table 2.1 Assumed cost of transportation on motor truck haul roads

Av. speed of vehicles	Cost of transportation per km of road length		Curve increment	Cost of transportation per km bee-line
	Timber transport	Movement of people		
km/h	%	%	%	%
40	63	420	5	80
30	84	450	6	90
25	100	490	7	100
20	125	520	8	110
15	166	580	10	130
10	250	630	12	155

Source: Table 6, page 24 Larsson and Rydstern (1968)

Table 2.2 Road cost per kilometre of road length

Av. speed of vehicles km/h	Cost of construction %	Annual cost of maintenance % (1)	
40	139	143	(2.0)
30	117	114	(1.9)
25	100	100	(1.9)
20	83	86	(2.0)
15	67	71	(2.1)
10	56	64	(2.3)

(1) Figures in brackets are % for cost of maintenance relative to cost of construction

Source: Table 1, page 21 Larsson & Rydstern (1968) shown schematically as Figure 2.4, in order to determine at what width of forest such a road layout will be more economic than that shown in Figure 2.2. In the case analysed by Larsson (*op.cit.*) the length of road 'B' in Figure 2.4, at which a changeover to a system of primary and secondary roads is justifiable on the assumptions is as shown in Table 2.3.

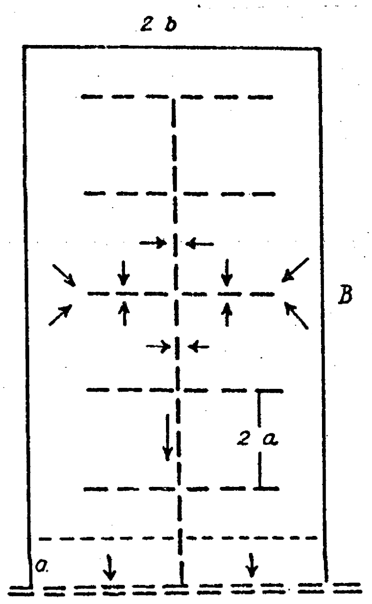


Fig. 2.4 Schematic layout of a road system of parallel primary motor truck haul roads and secondary motor truck haul roads at right angles to the primary roads

Table 2.3 Length of road at which a changeover to a system of primary and secondary roads is economically justifiable on the assumptions made in the average case

Average production m^3/ha	Length of road (B) km
2	12.4
3	10.4
4	9.5
5	8.7
6	8.1
7	7.4
8	6.8
9	6.4
10	6.1

Source: Larsson (1959) Table 5, page 58

Larsson (*op.cit.*) follows the definitive theoretical framework summarized above to undertake an analysis of 'losses due to non-optimum conditions' which is essentially a sensitivity analysis. He deals with the 'order of magnitude of the losses which are due to the fact that the road system is not designed in accordance with an optimum layout in one or several respects'.

a. Losses due to non-optimum road spacings

The results of the analysis are shown in Appendix 2.3 and Larsson (*op.cit.*) concludes:

> 'so long as the variation in road spacing about its optimum value is comprised within moderate limits, the order of magnitude of the losses due to non-optimum road spacings remains small'.

b. Losses due to non-optimum road standard

The results of the analysis are shown in Appendix 2.4 and Larsson (*op.cit.*) concludes 'that comparatively moderate deviations from the optimum value result in relatively tolerable losses'.

c. Losses due to inadequate adaption of road standard to variations in traffic volume

The results of the analysis are shown in Appendix 2.5 and Larsson (*op.cit.*) concludes 'that road standard adaption is particularly necessary when the roads are long and the loss amounts to such a high percentage of the cost of roads that it is undoubtedly worthwhile to try to ensure an adequate adaption of the standard in the longitudinal direction of the road during its construction as well as in the course of its annual maintenance'.

In the subsequent work Larsson and Rydstern (*op.cit.*) made a more detailed investigation of the magnitudes and the directions of changes in an optimum system layout due to variations in some of the basic factors. In the same study further road system layout models and simplified formulae were presented which the authors concluded gave results fully satisfactory for practical planning of forest road systems.

The cost elements which were varied in the analysis by Larsson and Rydstern (*op.cit.*) were as follows:

(a) the cost of transportation of timber in the forest area

(b) the cost of conveyance of labour in the forest area and on motor truck haul roads

(c) the cost of transportation of timber on truck haul roads

(d) capital cost of roads

(e) cost of road maintenance.

The analysis was based on variations in the cost elements associated with the derivation of the optimum road layout by the mathematical formulations of Larsson (*op.cit.*). The relations between production and the length and range of the roads associated with the optimum layout schematically represented in Figure 2.2 have already been noted and presented as Appendix 2.2 (*op.cit.* p. 72).

The results of the analysis are shown in Figures 2.5,2.6,2.7,2.8 and 2.9. It must be emphasized and after Larsson and Rydstern (*op.cit.*) page 40, that the relations deduced from the above analysis are not general but are dependent on the initial assumptions which were chosen for that analysis.

The results showed that even considerable changes in the individual cost elements produce moderate changes in the total cost of roads and the cost

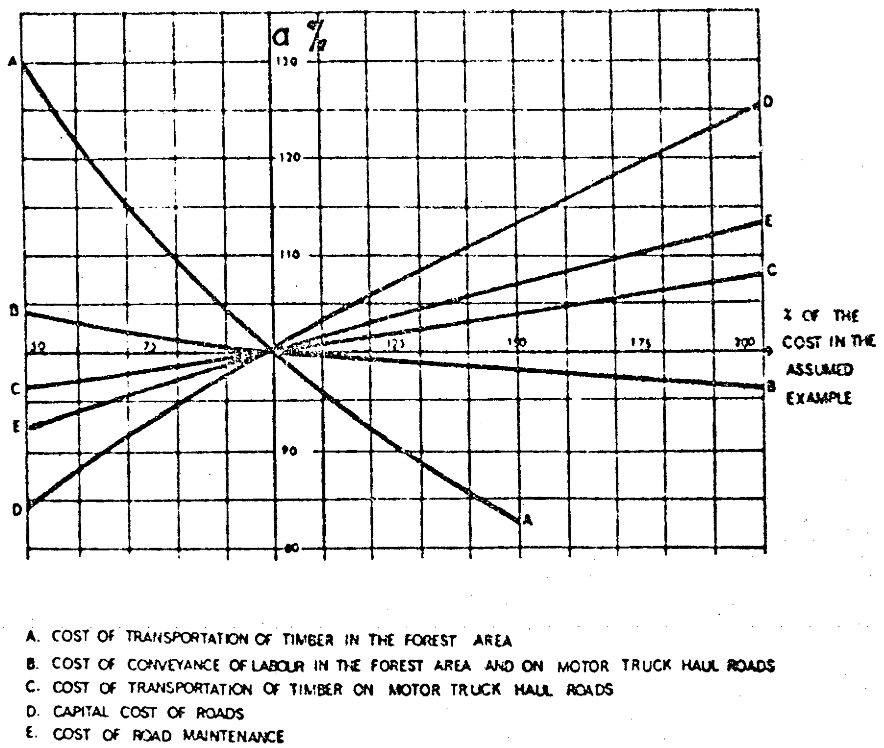


Figure 2.5 Variations in the optimum range of roads, a, due to variations in the cost elements A to E. Source: Larsson and Rydstern (1968)

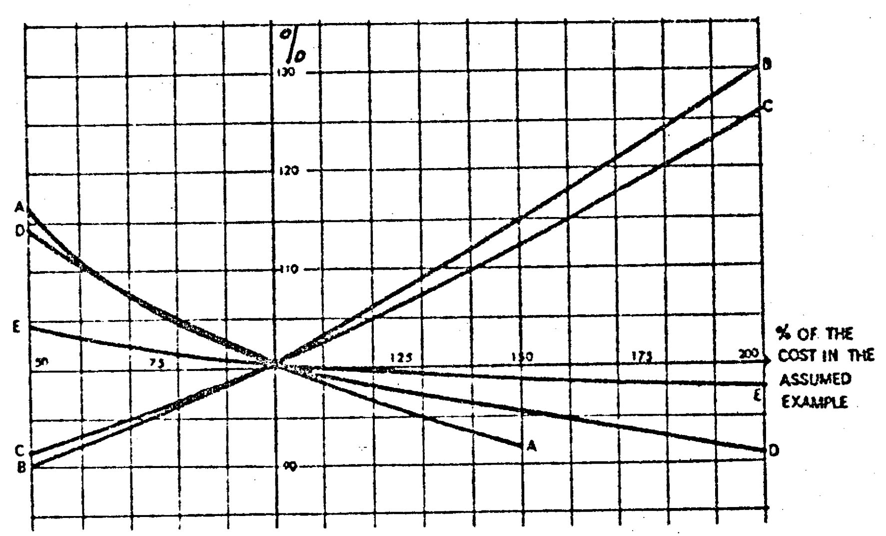


Figure 2.6 Variations in the average optimum road standard, expressed in terms of the average speed of transportation of timber, in Km per hour, due to variations in cost elements A to E (Figure 2.5) Source: Larsson and Rydstern (1968)

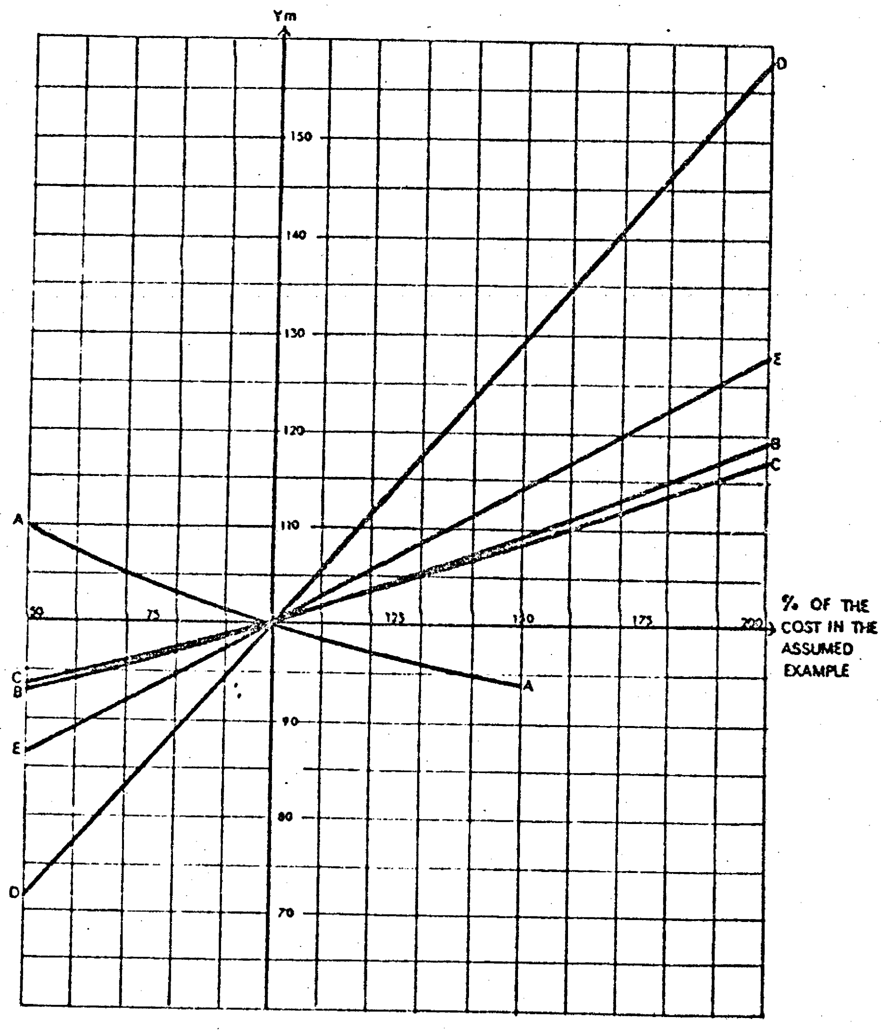


Figure 2.7 Variations in the average road standard, expressed in terms of the annual cost of roads per kilometre, Ym, due to variations in the cost elements A to E. Source: Larsson and Rydstern (1968)

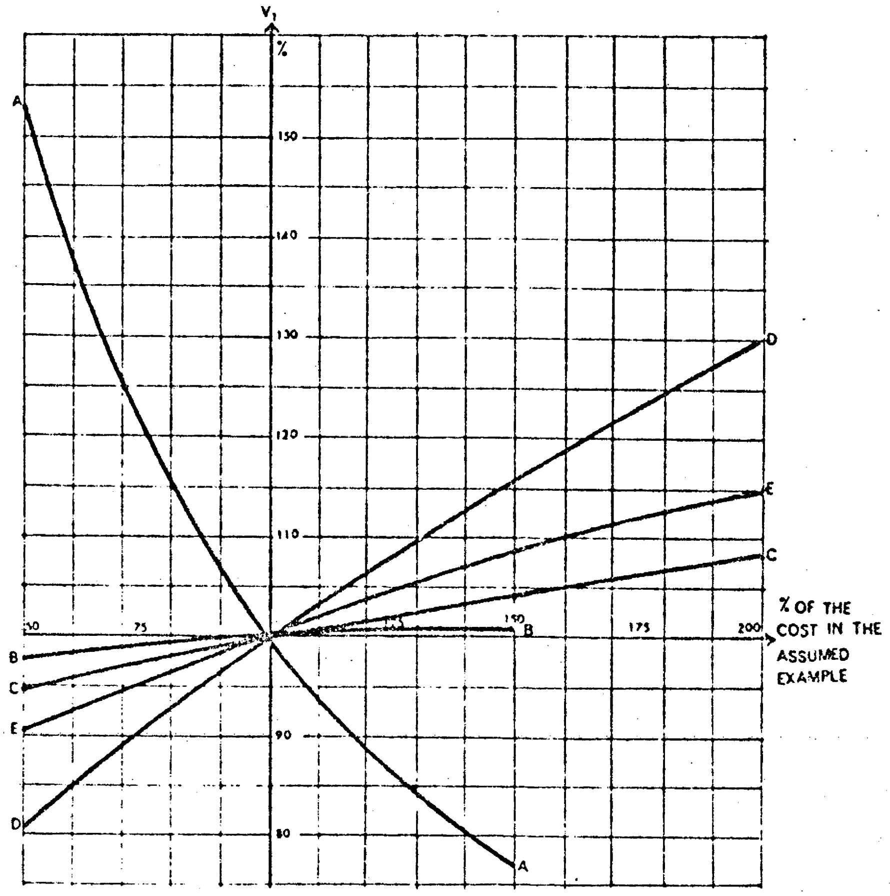


Figure 2.8 Variations in the optimum road shortening, V_1, due to variations in the cost elements A to E. Source: Larsson and Rydstern (1968)

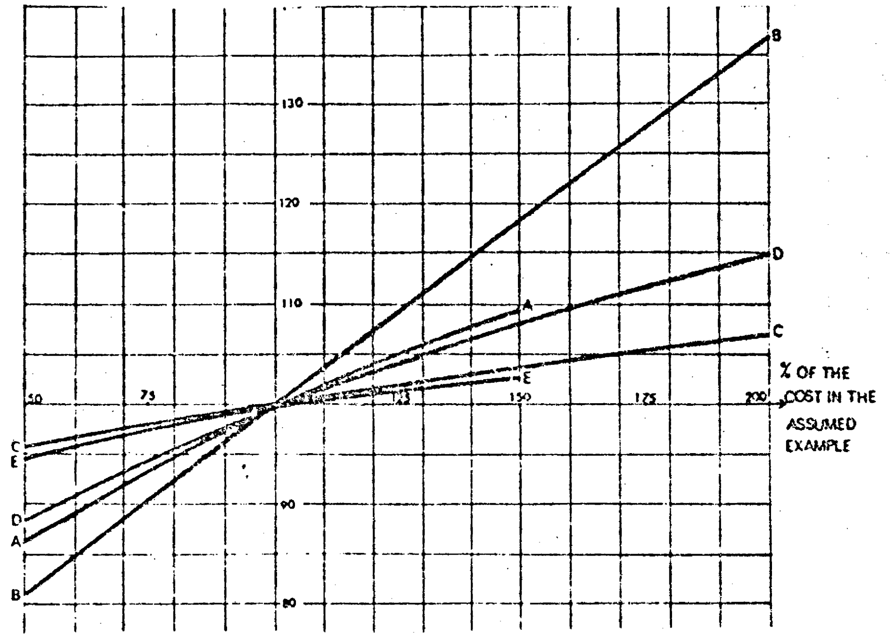


Figure 2.9 Variations in the sum of the cost of roads and the cost of transportation, K_{vf}, due to variations in the cost elements A to E.

of transportation but it should be noted that in deriving the results from a change in one individual cost element adjustments were made to all the parameters in the layout, that is a new optimum layout is calculated. For example, as indicated in Table 2.4, changes in the cost of transportation in the forest should result in changes in the cost of roads per unit length as with a changed spacing there will be either increased or decreased traffic volumes on the road. A decreased snigging cost for example should entail wider spacings of roads and therefore higher traffic volumes and therefore higher standards although the total length of road would be reduced.

Table 2.4 Response of road system layout to variation of transportation of timber in forest area

	Cost of transportation of timber in forest area, in per cent of the corresponding cost in the assumed example				
	50	75	100	125	150
Optimum range of road	131.4	112.0	100.0	90.3	82.7
Road standard (speed)	115.2	105.7	100.0	95.2	91.6
Cost of roads	110.4	104.0	100.0	96.7	94.1
Road shortening	153.3	119.6	100.0	86.7	77.3
Sum of cost of roads and cost of transportation	86.4	93.5	100.0	104.8	109.4

Source: Larsson and Rydstern (1968) page 36

2.3 REVIEW OF ANALYTICAL PROCEDURES FOR FOREST ROAD PLANNING AND DESIGN

Three main documents incorporating the methods formulated and presented by, in order, Matthews (1942), Larsson (1959) and Larsson and Rydstern (1968) have been briefly reviewed. The theoretical limitations of the methods put forward by Matthews (*op.cit.*) have been noted as have some of the practical requirements and difficulties associated with the application of the rigorous mathematical methods presented in Larsson (*op.cit.*) and Larsson and Rydstern (*op.cit.*).

The question that must now be faced in relation to the literature review is whether or not the methods can be adapted to evaluate the efficiency of the transportation networks and road standards which have resulted from the existing planning procedures and practices in the Prome Agency in Burma, this being the first step toward the major objective of this study which is the development of procedures to plan and design the most appropriate road system. The comprehensive and rigorous analysis formulated by Larsson (*op.cit.*) and developed in Larsson and Rydstern (*op.cit.*) make this approach the most attractive and the examination of the road system in some of the compartments in the Prome Agency is begun from this standpoint in Chapter 3.

To recapitulate, direct application of the Larsson (*op.cit.*) method requires, *inter alia*, expression in mathematical terms of the relationship between cost of snigging and the distance snigged and between cost of road construction and the cost of road transportation. The relations determined by Larsson and Rydstern (*op.cit.*) are shown by way of example in Figures 2.10 and 2.11. With these relations established it is possible to calculate an optimum network in terms of spacing and road standard for the schematic diagram shown in Figure 2.4. It is implied that for a practical approach the geometrical parameters of the actual layout to be evaluated or designed conform to the schematic diagram of the model.

It must also be noted in this review, for it represents a valuable tool for the evaluation of existing forest road systems, that the solutions

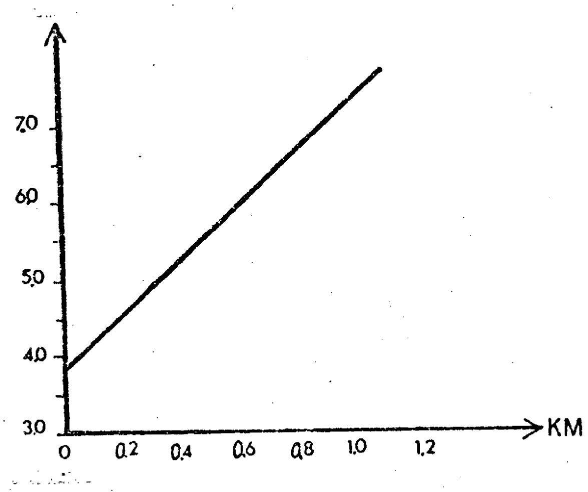


Figure 2.10 Relationship between cost of snigging and skidding distance
(after Larsson and Rydstern (1968))

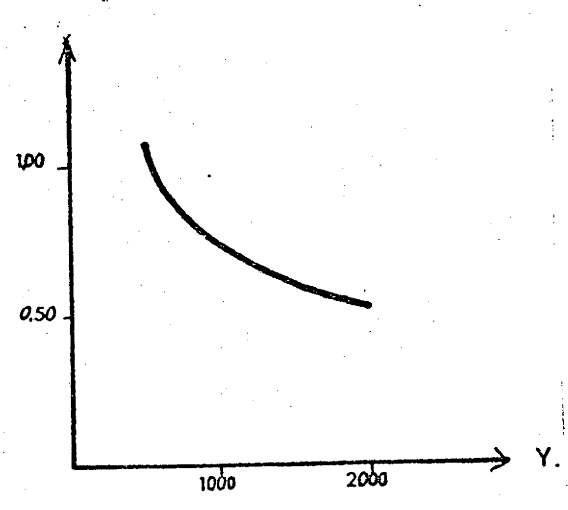


Figure 2.11 Relationship between cost of roading and cost of road transportation
(after Larsson and Rydstern (1968))

of mathematical equations formulated by Larsson (1959) and Larsson and Rydstern (1968) provide that the cost of road construction and the cost of transportation along the roads are equal, that is they are at the break even point. However it should be further noted that the mathematical equations do not explicitly separate any fixed costs, that is all costs vary in this case with spacing.

2.4 SUMMARY

It is concluded on the basis of a study of the literature that the following methods may be appropriate as analytical tools in the evaluation of the efficiency of the road system in the Prome Agency.

(1) Methods after Larsson (1959) provided that the necessary mathematical relations can be determined and that it can be accepted that the actual layout conform to schematic layouts analysed by Larsson and Rydstern (1968), not all of which have been reviewed.

(2) That the cost of road construction at any section expressed as a cost per cubic metre of wood should equal the cost of transportation per cubic metre, when other uses of the road can be disregarded, that is, the road is considered as of utility only in relation to the transport of harvested wood.

(3) Cumbersome cut and trial optimising procedures but with no guarantee that the least cost obtained is the optimal solution ensuring the minimum cost of extraction of the wood.

It is also appropriate at this stage to note methods or analytical tools which are suggested in the literature but which must be considered as approximations.

(4) Calculations of the spacing of the roads by balancing road costs with variable snigging costs. This effectively reduces the calculation of road spacing to use of the formula

$$a = \sqrt{\frac{y}{p.t_r}} \qquad (2)$$

and already referred to on page 70.

(5) The working rule suggested by several writers, including Silversides (1949) that the cost of the road should equal cost of road transportation should equal cost of snigging. This procedure follows as a consequence of (2) and (4) above.

It is also appropriate to restate the reason for (3) above being an approximation and to examine the results obtained by Larsson and Rydstern (1968) in relation to it. Essentially (3) is approximate in that it constitutes a step procedure. One cost (snigging) is balanced against another (roads) to determine spacing and then the cost of roads is balanced against cost of transportation. What is required is that the minimum of the sum of the three costs be determined, as is done by Larsson (1959).

While Larsson (1959) and Larsson and Rydstern (1968) undertook sensitivy analyses,and which have been reviewed,they did not examine the balance between snigging cost and the cost of roads and the cost of transportation in their optimal solutions and compare it with the approximate solution stated as (5) above.

CHAPTER 3

EVALUATION OF WOOD TRANSPORT SYSTEMS IN THE PROME AGENCY, BURMA

3.1 INTRODUCTION

The general description of the forest operations in Burma presented in Chapter 1 with a particular orientation toward wood transportation suggests many avenues for research. This study concentrated on wood transportation along forest roads.

The review of the analytical techniques for the planning of forest roads presented in Chapter 2, led to the conclusion that an approach based on rigorous mathematical formulation was the most attractive.

The Prome Agency was chosen as a study area to examine the feasibility of applying the analytical techniques, reviewed and summarized in Chapter 2, to evaluate the efficiency of the transport networks that have been constructed for logging compartments in the Agency. There were some compelling reasons for this choice.

1. Firsthand experience of the design and operation of the logging and transport systems,
2. data associated with the past practice could be readily obtained on a personal basis.

3.1.1 Prome Agency

Prome Agency is situated in south Central Burma (Figure 1.1). It is one of thirty five extraction agencies, that is geographic units defined by the Timber Corporation for administration of its timber extraction operations. The area contains about 232,000 hectares of mixed deciduous teak and hardwood forests. The hilly country makes logging access roads costly.

Climatically there are three distinct seasons:

(a) A dry and cool season from mid-October to mid-February when there is no rain at all,

(b) a dry and hot season from mid-February to mid-May,

(c) the wet season, known as the monsoon, from mid-May to mid-October.

Rainfall in the area is about 2000 mm (80") and the average minimum and maximum temperatures are respectively about 21°C (70°F) and 30°C (90°F). The extremes are about 43°C (110°F) in May and 5°C (40°F) in January.

There are extensive stands of high quality black stripe teak in the Agency and also stands of hardwoods such as pyinkado (*Xylia dolabriformis* Benth.), padauk (*Pterocarpus macrocarpus* Kurz.), commercially the most valuable hardwood species. The trees are felled according to the working plan. Only crosscut saws are used for felling and log making. The logs are removed from the stumps by means of elephants and buffaloes. Machines are not used in snigging from the stump to either floating streams or landings.

As Prome Agency is on the Irrawaddy river it is responsible for rafting operations. Dry teak logs are floated down in the streams and collected before they reach the main river, the Irrawaddy. These logs are formed into rafts at Prome and taken to Rangoon by towing launches.

Green teak and hardwood logs are transported by trucks. Road construction usually begins in November and trucking in late December. Most of the hardwood logs are sent to local sawmills for further conversion.

Green teak logs are sent to a rafting station or railway station and on to Rangoon.

3.1.2 Availability of Records

The volume of wood extracted and the cost of operations for a particular area, for example, the Paukkhaung Range, are kept in the Range office and the Agency office at Prome. Data collection at these offices was done during the six weeks allowed by the Colombo Plan Scheme for married overseas students as home leave.

3.1.3 The Objective of the Evaluation

Road construction costs, snigging costs and road transport costs are examined in relation to each other by means of a break-even analysis to provide a basis for the formulation of guidelines for planning policies for road construction, snigging and road transportation.

3.2 DATA COLLECTION

Assessment of current practice requires information on the costs of existing operations. The proforma shown in Appendix 3.1 was prepared to facilitate data collection. Data, including the compartment maps, skidding costs, roading costs and truck haulage costs were collected for seventeen compartments. The data are summarized in Appendix 3.2.

3.3 COMMENTS ON DATA

The snigging costs per unit volume (log ton = 1.805 m^3) were payments made by the authority because all the snigging operations are done by private contractors. The snigging costs for each particular compartment are therefore the actual costs for that compartment on the basis of a rate for one log ton.

The volume of timber for each compartment was recorded separately to the snigging costs and is the actual wood extracted from each particular compartment on the basis of the measurement of the logs.

The actual number of snigging power allocated to each compartment for the period of logging was also available and was recorded on the data collection sheet. The snigging powers used were buffaloes and elephants.

The snigging distance in each compartment varies of course from place to place but only the field estimate of the average snigging distance was available for a particular compartment. The field estimate is made by supervisory staff at the time of the field inspection of the compartment for planning the logging operation.

The road construction and haulage costs as collected are based on the total costs of each for a group of compartments. The actual road construction costs for particular compartments are not available because only lumped road construction costs, that is total costs for several adjoining compartments, are summarized at the Agency office. Roads in the compartments are seasonal roads and constructed by bulldozers. The costs are for the whole of road construction. Costs for formation, gravelling or surveying are not recorded separately. Similarly the haulage costs as collected are for the groups of compartments.

3.4 DATA ANALYSIS AND EVALUATION

3.4.1 Theoretical Approaches

As summarized in Chapter 2, application of the Larsson and Rydstern (1968) approach requires *inter alia,*

1. that the geometric layout of roads as constructed, conform to that in the schematic diagram used in the mathematical formulations,
2. that a mathematical relation be established between the skidding distance and the skidding cost,
3. that a mathematical relation be established between the cost of road construction and the cost of road transportation.

The data collected were examined in relation to each of the above requirements.

3.4.1.1 Geometric layout of constructed transport systems

The geometry of the road network associated with the theoretical formulations of Larsson and Rydstern (*op.cit.)* is as shown in Figure 2.1 and the formula for the spacing of the roads is given in Equation (2).

The theoretical spacing of the lateral roads as determined by the formula becomes applicable when the width of the forest from the main road is such that the construction of lateral roads and the associated reduced skidding distances result in a reduced wood transportation cost as compared to direct skidding. The width at which savings accrue from the construction of the lateral roads is after Matthews (1942) the maximum direct economic skidding distance and this is the theoretical spacing of the lateral roads. The theoretical formulations are shown and discussed in Appendix 3.3.

Thus in practical application as a tool for the evaluation of existing road networks, lateral roads should have been built at the optimum spacing wherever the width of the forest is greater than the theoretical spacing as determined by Equation (2). That is the three parameters volume of production, variable skidding cost per unit volume per unit distance and road construction costs per unit distance must be known.

The actual network of roads in Compartments 41, 42, 43 and 44 in the Prome Agency are shown in Figure 3.1. The road network is represented with the width of forest at each point along the road in Figure 3.2. The schematic representation of the actual network reflects of course the topography of the terrain. The 'spacing' between the lateral roads shown in Figure 3.2 as S_1, S_2, S_3 etc. is over many sections the distances between small valleys running out from the main road which is in valleys for a considerable proportion of its length.

If the three parameters volume of production, variable skidding cost per unit volume per unit distance and road construction costs per unit distance are known over the sections defined by the spacings shown as S_1, S_2, S_3 etc. then theoretical formulations could be used to evaluate the actual spacings against the optimum value.

Thus while there may be considerable diversity in the magnitudes of each of the three parameters along a forest road, because of for example such factors as different road costs and snigging costs and also differences between the bee line skidding distances and actual skidding distances, for relatively confined areas defined by selected sections of the road it could be accepted that the magnitude of the three parameters is represented by average values and these values then used to calculate the theoretical spacing. For example Figure 3.2 suggests that comparisons of actual with theoretical values of spacing could be made over the sections AB, CD, EF.

A 'strip map' was also prepared for Compartments 8, 9, 10, 11, 12 as shown in Figure 3.3. In terms of geometry the result is similar in principle to that for Figure 3.2. The actual network is schematically

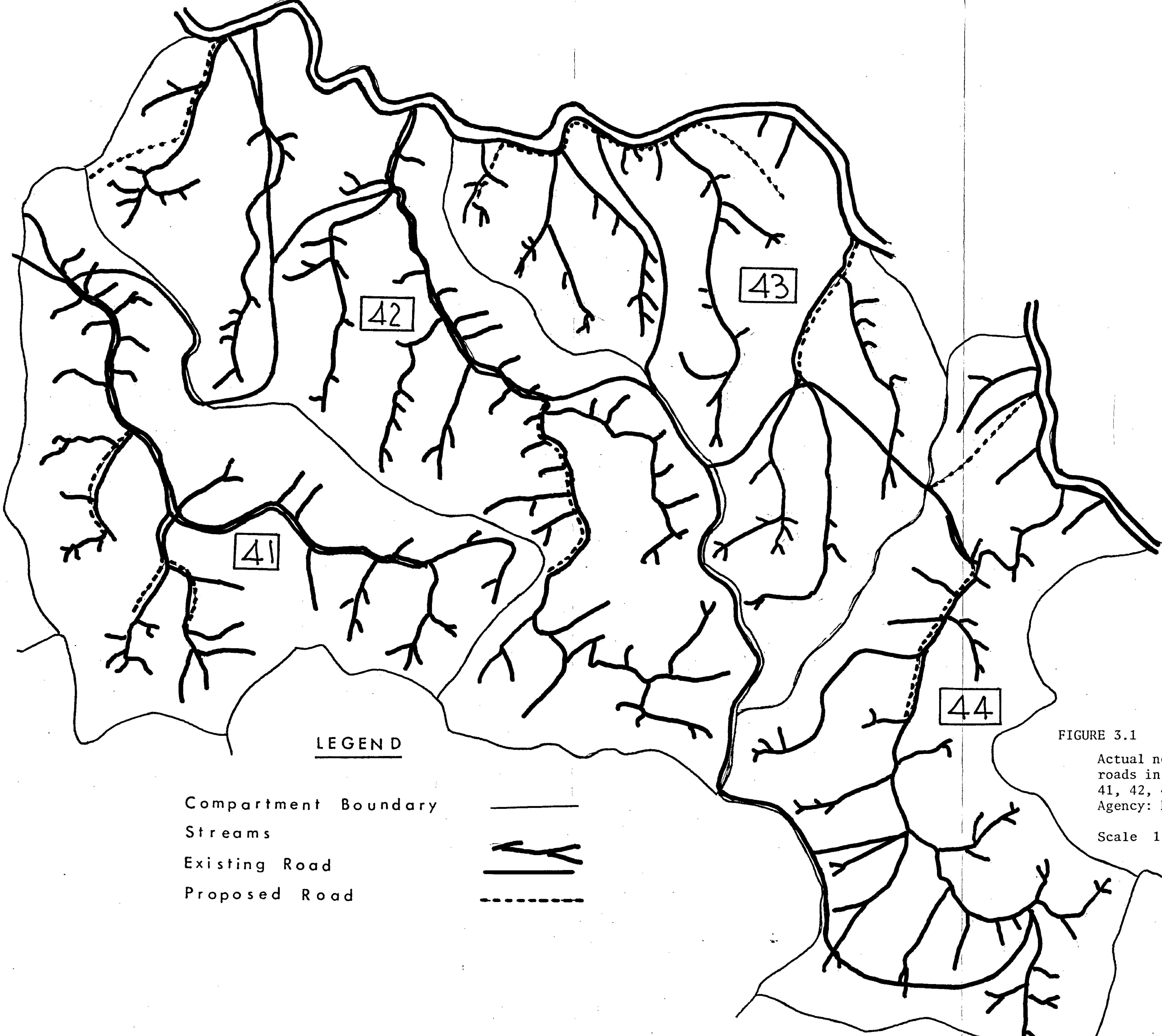


FIGURE 3.1

Actual netowrk of roads in Compartments 41, 42, 43, 44 Prome Agency: Burma.

Scale 1:1600

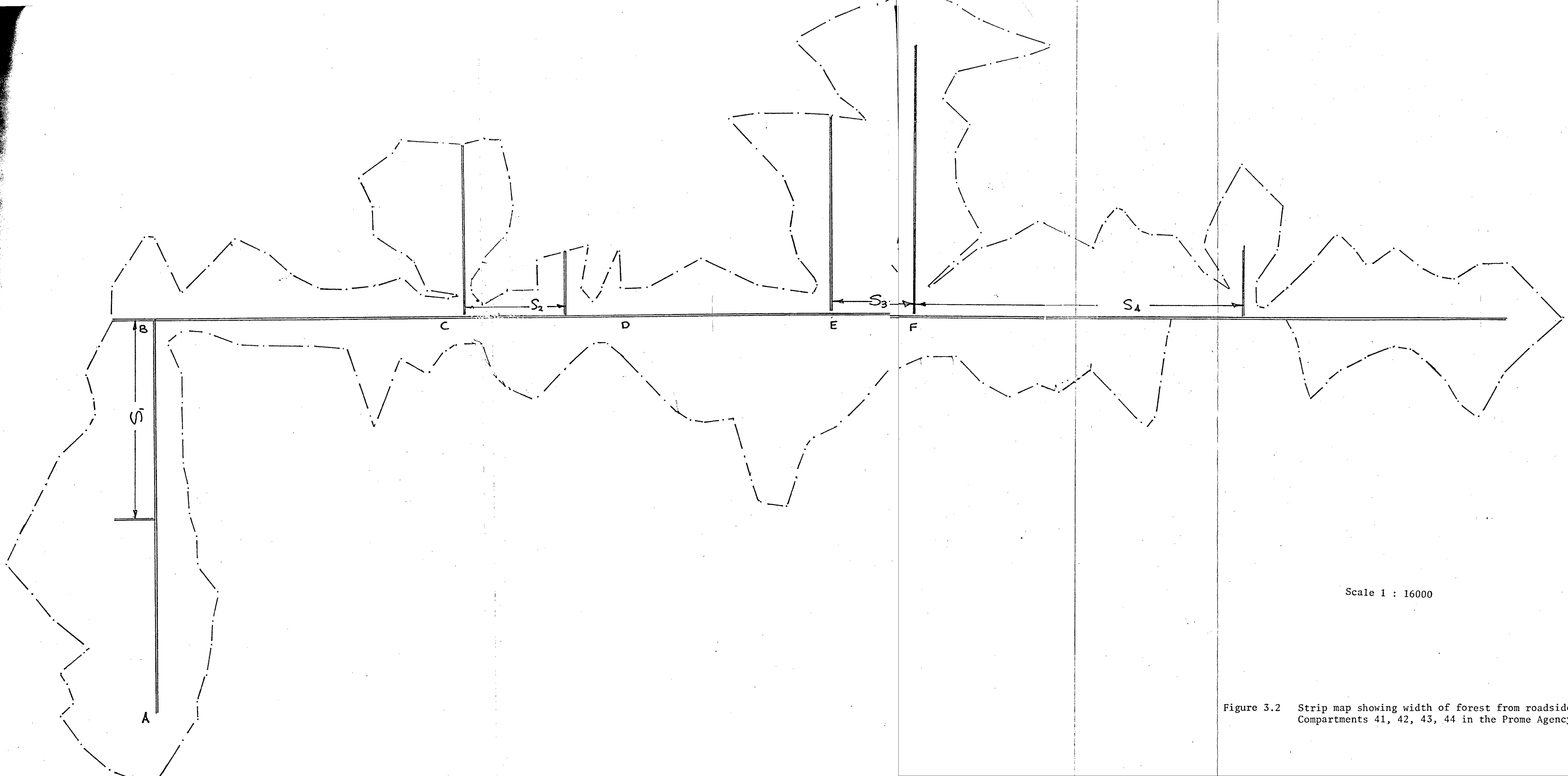


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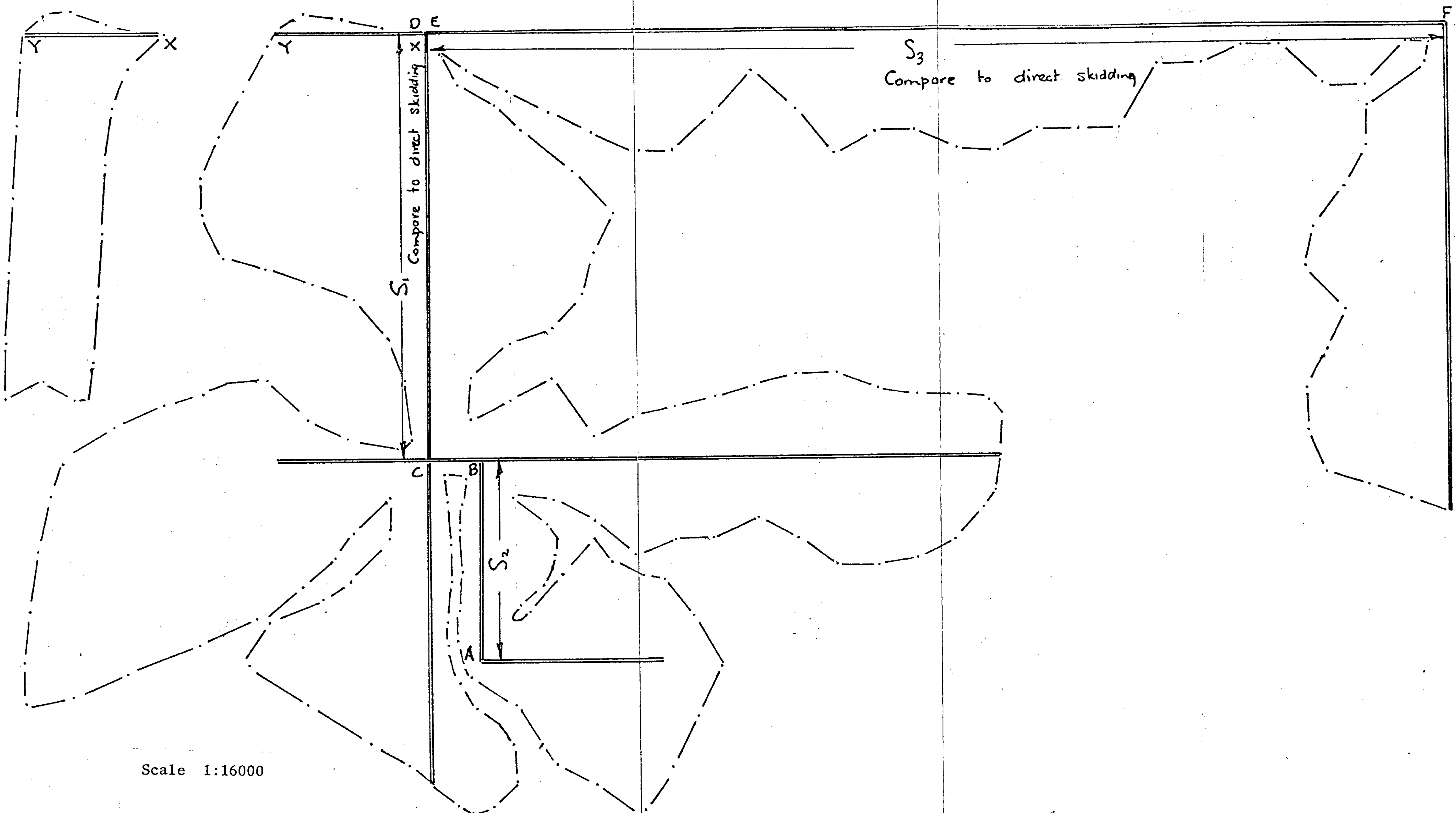
Figure 3.2 Strip map showing width of forest from roadside, Compartments 41, 42, 43, 44 in the Prome Agency, Burma



Scale 1:16000

Figure 3.3 Strip map showing width of forest from roadside, Compartments 8, 9, 10, 11, 12 in the Prome Agency, Burma represented in a form related to the Larsson and Rydstern (*op.cit.*) model with actual spacings of lateral roads. Thus Figure 3,3 also suggests that comparisons of actual with theoretical values of spacing could be made over the sections AB, BC, CD,

There is also support in the literature that even quite complicated road networks can be related to the representation of the model shown in Figure 2.1., for example Sundberg (1976).

It is concluded that the first requirement of the Larsson and Rydstern (*op.cit.*) approach, that is that the geometry of the actual road network can be represented by a layout which section by section conforms to the geometry of the theoretical model, could be met for the roads in the Prome Agency.

It is emphasised that it is not implied that the effort to formulate the representation and obtain the necessary information on the three parameters would be appropriate in practical terms for this would require further research and testing. As will be seen in the succeeding section there are insurmountable deficiencies in the data available in relation to other requirements of the Larsson and Rydstern (*op.cit.*) approach and testing of the practical application of this approach is not straightforward. Ultimately a more approximate technique than the rigorous analysis was adopted to examine if the balance between the components of the transportation costs, namely road construction, snigging and road transportation, is such as to provide for minimal transport cost per unit volume of wood delivered to the mill door.

Nevertheless the initial exploration of the geometry of the existing road networks suggests that, with accurate data collection and detailed studies to formulate the geometry, the Larsson and Rydstern (*op.cit.*) model could be used for the evaluation of existing networks.

3.4.1.2 Relation between skidding cost and skidding distance

Introduction

The data collected on the actual costs associated with the logging of the study compartments included as noted previously, the cost of skidding and the volume of production so that the total cost of skidding could be expressed as a cost per cubic metre for each compartment.

However there was no direct measurement of snigging distances. At the time of field reconnaissance of the compartment by staff of the Timber Corporation estimates were made of the average skidding distance in each compartment. The cost of skidding per cubic metre and the field estimates of the average skidding distances are shown in Table 3.1 and Figure 3.4.

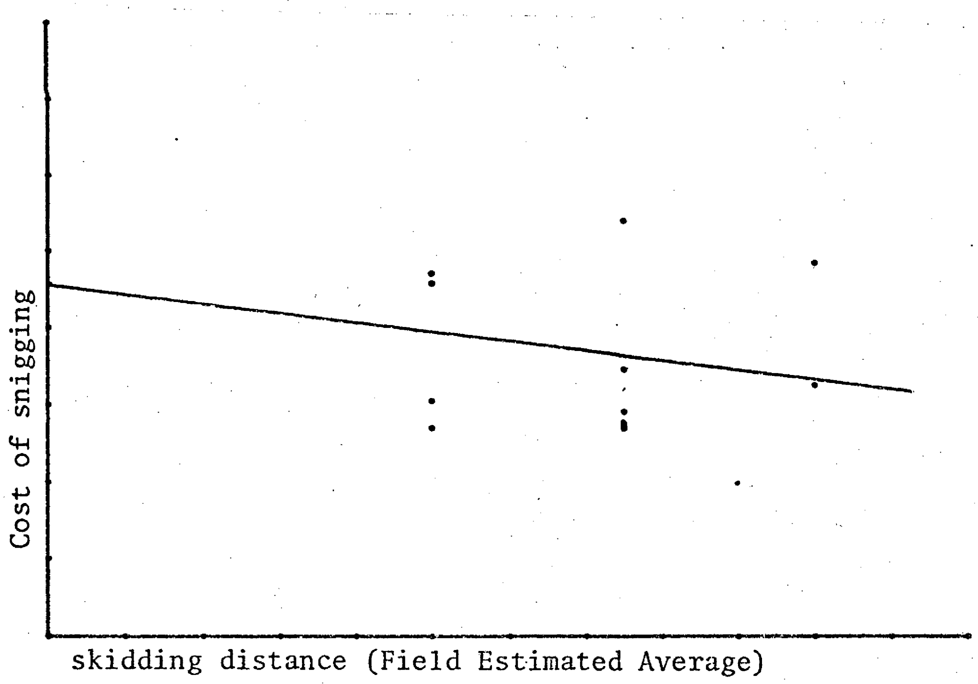


Fig. 3.4 Relation between cost of snigging and the field estimated average skidding distance.

The regression line shown in Figure 3.4 suggests that the costs of skidding per unit volume decrease with increased skidding distance. Given

Table 3.1 Cost of skidding and field estimates of skidding distance

Compartment No.	Skidding cost per m^3	Field estimated skidding distance
41	23.27	1200 metres (0.75 mile)
42	27.70	1200 " (0.75 ")
43	26.04	1600 " (1.00 ")
44	24.38	800 " (0.50 ")
22	38.28	1600 (1.00)
23	36.57	800 (0.50)
25	36.57	800 (0.50)
26	37.67	800 (0.50)
29	37.67	800 (0.50)
30	43.21	1200 (0.75)
36	37.67	800 (0.50)
8	21.88	1200 (0.75)
9	27.70	1200 (0.75)
10	21.61	1200 (0.75)
11	21.61	1200 (0.75)
12	21.61	800 (0.50)
23	22.16	1200 (0.75)

similar terrain and snigging methods this must be an erroneous deduction from the data.

It will be noted from Table 3.1 and Figure 3.4 that there are only three values for the field estimates for the average snigging distances, 800, 1200 and 1600 metres. That is they are to the nearest say 400 metres (a quarter of a mile). It was concluded that the field estimates of skidding distances may not be an adequate basis for reaching any conclusion regarding the relation between skidding costs and skidding distances. To establish if there was any significant relation between snigging costs and snigging distance it was therefore necessary to estimate the snigging distances in a more accurate way. Field measurements of actual skidding distances could not be undertaken for the data collected during home leave. Estimates, described as synthetic skidding distances, were therefore derived.

Procedures for Deriving Synthetic Skidding Distances

Two methods were tested for deriving estimates of synthetic skidding distances.

(1) Drawing grid lines on the compartment maps,

(2) sketching the assumed actual skidding paths on the compartment maps.

(1) Drawing grid lines on the compartment map

The compartment maps used in this study, and prepared in connection with the planning of the logging operations, are to a scale of 4 inches to one mile, that is one cm is equal to about 160 metres on the ground. To determine the average synthetic skidding distance gridlines at spacings of 400 metres, 200 metres and 100 metres were drawn on the compartment maps.

For the 100 metre spacing 0.6 cm (0.25 inch) squares were drawn on tracing paper and placed over the compartment map with roads. The shortest distance from the centres of the squares to the road were measured with a scale rule. These distances were taken as representing bee-line synthetic skidding distances for individual trees. The mean of all the distances was treated as an average skidding distance for that compartment, that is it was assumed that the logs to be snigged are evenly distributed over the area. For 200 and 400 metre spacing 1.2 cm (0.5 inch), 2.5 cm (one inch) squares were drawn respectively on tracing paper and the same procedure followed as for 100 metre grid lines. The overlay with 100 metre grid lines and the map for Compartment 10 are shown for example as Figure 3.5.

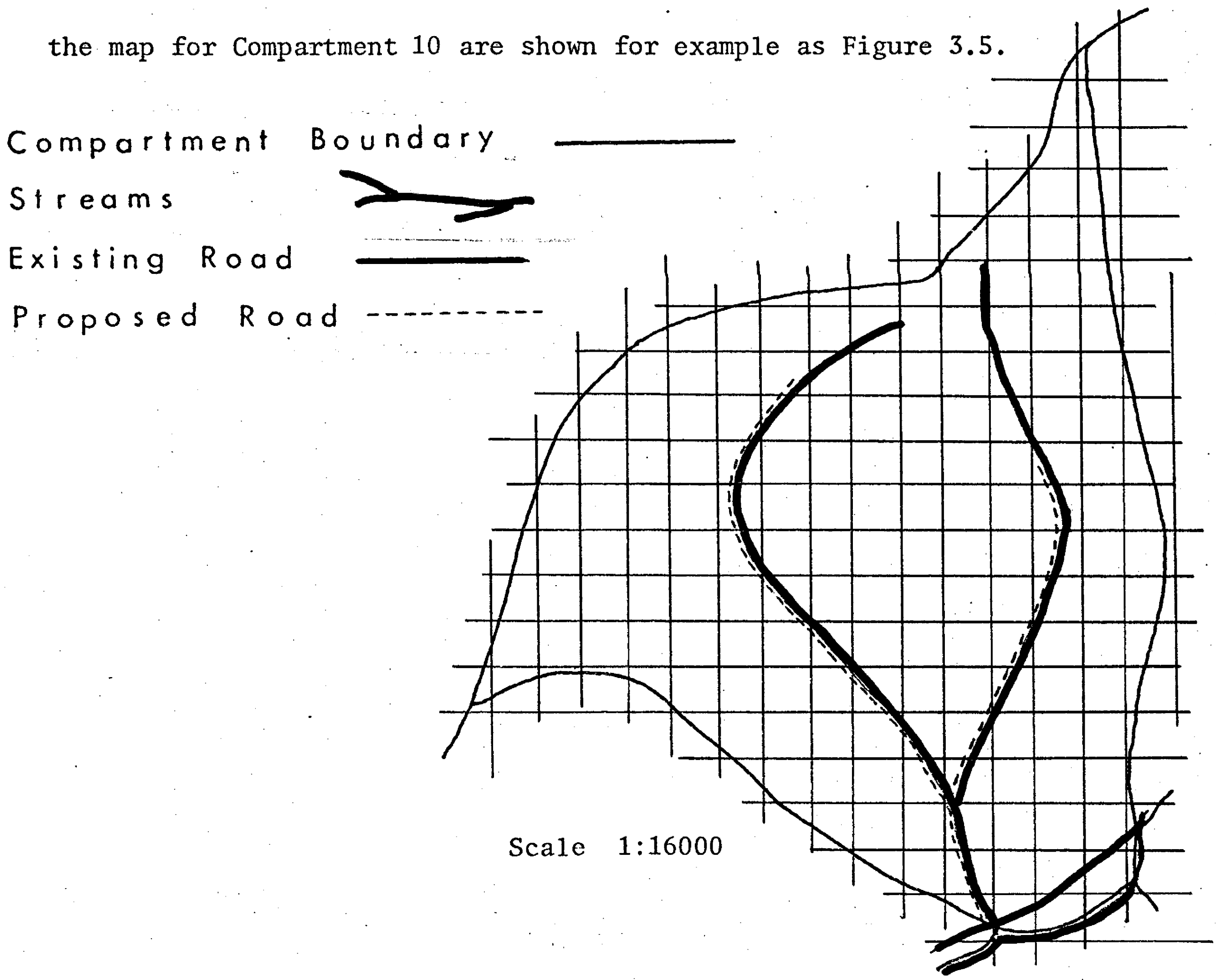


Fig. 3.5 Map of Compartment 10 showing grid lines for deriving synthetic skidding distances to the road.

(2) Estimating the skidding distances by assuming the actual skidding paths

Skidding paths for the animals usually follow the tops of ridges and descend into the valleys as soon as more open country is reached. Then they frequently follow the small feeder streams. Therefore actual skidding paths could be estimated by observing the maps. The compartment map was divided into sub-areas and the assumed skidding path from the centre of each sub-area determined the estimated skidding distance. The mean of distances from the sub-areas to the road was taken as the average synthetic skidding distance for that compartment.

The two methods were tested on Compartments 41, 42 and 43 and the results are shown in Table 3.2. While in fact the total number of skidding trips from each compartment was in excess of the number of intersections on the 100 metre grid lines it was decided, mainly on the basis of the time involved, that the 100 metre grid lines would serve for initial investigations for appropriate procedures.

Synthetic skidding distances were therefore determined by the two methods, that is from 100 metre grid lines and chosen actual skidding paths.

The statistical parameters associated with derived skidding distances, viz. mean standard error, standard deviation, variance, kurtosis and skewness are shown for each compartment in Appendix 3.4.

There can of course be no valid comparison of the mean derived skidding distances with the mean of the actual skidding distances without field measurements of the actual skidding distances.

However Table 3.2 shows that the estimates derived with 100 m grid spacings are similar to those derived from the assumed actual skidding paths.

Table 3.2 Mean Synthetic Skidding Distances

Compartment No. [1]	Mean Skidding Distance (metres)			
	Method 1			Method 2 [3]
	100 m^2 grids [2]	200 m^2 grids [2]	400 m^2 grids [2]	Assumed Actual paths
41 (1841)	240 (259)	296 (73)	258 (18)	286 (7)
42 (2064)	329 (384)	358 (106)	311 (24)	356 (8)
43 (1270)	270 (275)	267 (74)	307 (19)	315 (5)
44 (1377)	287 (292)	-	-	328 (3)
22 (629)	359 (276)	-	-	388 (3)
23 (813)	408 (310)	-	-	405 (4)
25 (1821)	340 (276)	-	-	325 (4)
26 (1191)	395 (228)	-	-	502 (4)
29 (308)	230 (272)	-	-	278 (5)
30 (297)	658 (310)	-	-	641 (3)
36 (2376)	588 (571)	-	-	573 (5)
8 (1196)	219 (262)	-	-	208 (4)
9 (1228)	660 (197)	-	-	650 (2)
10 (669)	884 (157)	-	-	823 (3)
11 (1065)	371 (207)	-	-	358 (2)
12 (2502)	188 (311)	-	-	187 (3)
23 (6701)	260 (620)	-	-	297 (6)

1) Figures in brackets show the actual number of logs extracted from the compartment

2) Figures in brackets show the number of grid intersections for which an estimate of the synthetic skidding has been made

3) Figures in brackets show the number of sub-areas selected and thus the number of paths traced on the compartment

If the trees are uniformly spread then as the grid spacing decreases and the number of grid intersections approaches the number of trees it could be assumed that the derived value will more accurately approach the actual value. Nevertheless the scale of the map precludes great precision. Since the immediate objective is to examine for a relationship between actual snigging costs and an estimate of snigging distances the 100 m grid spacing values were adopted to examine for any significant relation.

The snigging costs and the mean synthetic skidding distances are shown for each compartment in Table 3.3. However the test for linearity of the relation between the costs and the distances (shown dotted in Figure 3.6) was not significant. The correlation coefficient was only 0.21. It is suggested that this may be because of the wide variation in skidding costs with respect to skidding distance, for example between Compartment 29 and 10.

Table 3.3 Cost per cubic metre and the average synthetic skidding distance for each compartment

Compartment No.	Skidding cost per cubic metre ks.	Average skidding distance(1) (synthetic) m
41	23.27	240
42	27.70	329
43	26.04	270
44	24.38	287
22	38.78	359
23	36.57	408
25	36.57	340
26	37.67	395
29	37.67	230
30	43.21	658
36	37.67	588
8	21.88	219
9	27.70	660
10	21.61	884
11	21.61	371
12	21.61	188
23	22.16	260

(1) Based on 100 m grid lines

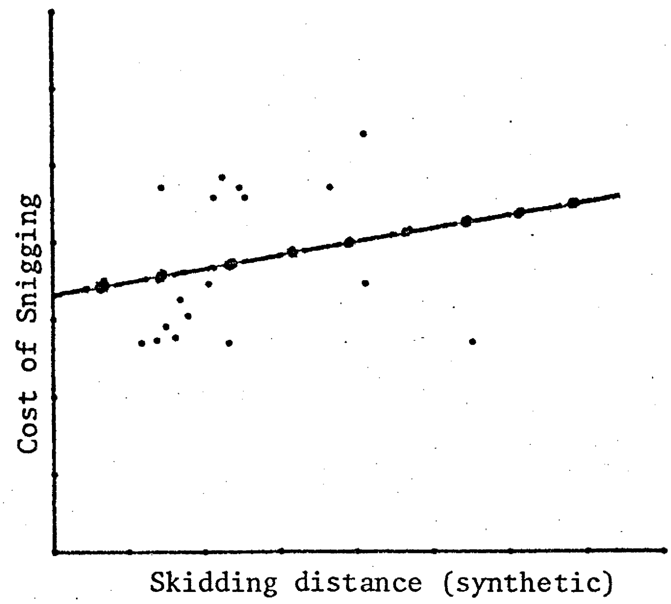


Fig. 3.6 Relationship between cost of snigging and skidding distance (synthetic)

However it is suggested that with accurate data collection a mathematical relation may be established between the skidding distance and the skidding costs in the compartments of the Prome Agency and thus meet the second requirement for application of the Larsson and Rydstern (*op.cit.*) approach.

There are other points of interest associated with the synthetic skidding distances and these will be discussed later for here it is only questioned whether or not it is possible to establish the third requirement of the Larsson and Rydstern (*op.cit.*) approach, the relation between road construction costs and road haulage costs.

3.4.1.3 Relation between road construction costs and road haulage costs

The data collected on the actual costs associated with the logging of the compartments also included, as discussed previously, the costs of road construction and road haulage.

(i) Derivation of road construction costs

The accounting of the construction costs does not enable breakdown into compartments and the only data available on road construction costs for the compartments selected for study are as shown in Table 3.4.

Table 3.4 Road construction costs

Compartment No.	Total roading costs (kyats)
41, 42, 43, 44	111,881.29
22, 23, 25, 26, 36	149,923.20
29, 30	10,013.02
8, 9, 10, 11, 12, 23	84,816.46

The roads constructed for selected compartments are shown in Appendix 3.5, maps 3.1 to 3.9. Average construction costs are shown in Table 3.5. The lengths of road were measured on the maps and are also shown in Table 3.5.

Table 3.5 Average road construction costs and length of road

Compartment No.	Length of road (km)	Average road construction cost per kilometre (kyats)
41, 42, 43, 44	76.8	1456.79
22, 23, 25, 25,36	99.7	1503.67
29, 30	10.7	936.14
8, 9, 10, 11, 12, 23	8.1	1044.73

(ii) Derivation of road haulage cost

As for the road construction costs, the accounting of the costs of haulage did not enable breakdown by compartments and the data on road haulage costs for the compartments selected for study are as shown in Table 3.6.

Table 3.6 Road haulage cost

Compartment No.	Total haulage cost (kyats)
41, 42, 43, 44, 22, 23)) 25, 26, 29, 30, 36)	757,056.44
8, 9, 10, 11, 12, 23	360,390.71

These costs were for haulage to the mill and therefore include a component for haulage along lengths of road (actually sealed roads) which are not included in the costs of road construction shown in Table 3.4.

(iii) Relative costs per unit volume for road construction and road haulage

The estimates derived for the road haulage costs associated with haulage over the roads for which the costs of construction are known, as shown in Table 3.7, provide the basis for the costs shown in Table 3.8.

Table 3.7 Costs of road construction and road haulage

Compartment No.	Road construction cost kyats/km	Road haulage cost kyats/m^3/km
41	1460	0.49
42	"	0.48
43	"	0.46
44	"	"
22	1500	0.49
23	"	"
25	"	0.52
26	"	"
29	940	0.52
30	940	"
36	1500	0.49
8	1050	0.86
9	"	"
10	"	0.79
11	"	0.84
12	"	0.76
23	"	0.61

Table 3.8 Costs per unit volume for road construction and road haulage

Compartment No.	Cost of roads per unit volume (kyats/m^3)	Estimated cost of haulage[1)] per unit volume (kyats/m^3)
41	2.42	1.86
42	4.31	3.19
43	4.28	1.86
44	2.97	1.55
22	8.14	2.27
23	5.20	1.88
25	1.31	1.26
26	2.51	1.47
29	18.07	3.88
30	6.81	1.47
36	1.24	1.45
8	5.00	4.49
9	1.26	1.30
10	0.70	0.31
11	3.70	2.59
12	3.27	5.44
23	1.09	4.60

1) An allowance for road haulage along public roads has been deducted from the total haulage cost to obtain an estimate of haulage cost along the forest roads

The method adopted to derive road haulage costs was as follows. The State Timber Corporation uses standard road haulage rates for wood transportation along sealed roads in the preparation of estimated costs for the harvesting of wood. These estimates are used in the assessment of tenders. The actual costs of wood transportation shown in Table 3.6 were recalculated to the cost of hauling over the roads constructed for harvesting the compartments by subtracting from the hauling cost an estimated cost of hauling over the sealed roads.

There is no basis for differentiating between compartments for road costs per unit length. This could be done if actual data were kept but the field experience does not suggest any change in the standard of construction of the roads nor in general substantial changes in the topography. Theoretically and also desirably in practice of course there should be changes in the standard of construction; specifically a decrease in the standard of the road and hence the construction cost as the road moves into the forest, but this has not been the practice in the Prome Agency.

Accepting that road construction costs are uniform per unit length the total cost of road construction can be pro-rated to each compartment on the basis of the length of the road as measured on the maps and then expressed as a cost per unit volume.

The unit rates shown in Table 3.7 are also shown in Figure 3.7.

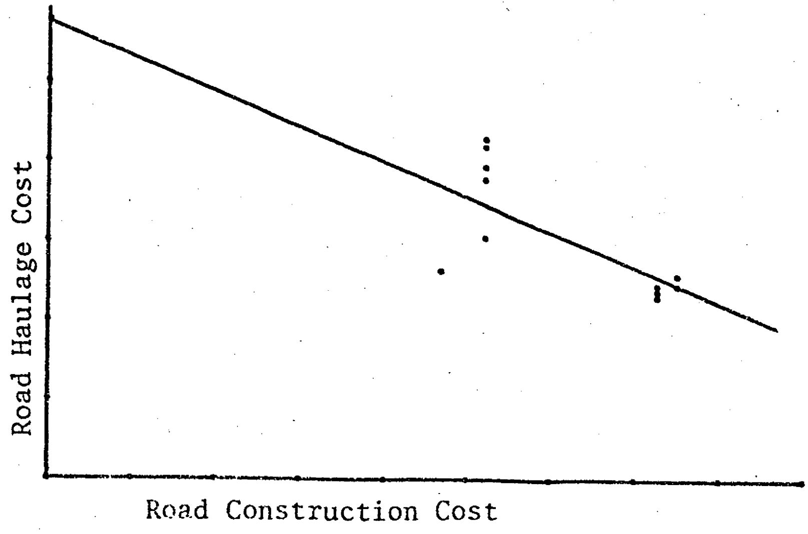


Figure 3.7 Relationship between road haulage cost and road construction cost.

It is accepted that there is insufficient data to determine the form of the relationship between haulage cost and roading costs. However it is notable that there is no indication that the relationship would not conform to that shown in Figure 2.4 after Larsson and Rydstern (*op.cit.*). As noted previously a formula for the relationship as shown in Figure 2.4 is necessary for the mathematical derivations presented in Chapter 2 to be applicable.

3.4.1.4 Summary

The study of the data collected suggests that in the Prome Agency the geometry and the relationship between skidding costs per unit volume and skidding distance would meet the theoretical requirements of the rigorous mathematical approach formulated by Larsson and Rydstern *(op.cit.)*.

However, there is insufficient data to reach any conclusion regarding the relationship between haulage cost per unit volume and road construction costs per unit length and the rigorous approach to the evaluation of the network cannot therefore be pursued with the data available.

Nevertheless there are indications that, with well designed and controlled cost accounting and data collection procedures, the necessary relationship could be established and the rigorous approach applied. This is the obvious course to take for further research but it was impracticable to obtain the field data in the Prome Agency in connection with this study.

3.4.2 Empirical Approaches: Evaluation of the Balance between Skidding Costs and Road Construction Costs and Road Haulage Costs

In the review presented as Chapter 2 of the analytical procedures for the planning and design of forest roads it was noted in summarizing that there is a 'working rule suggested by several writers, including Silversides (1949) that the cost of the road should equal the cost of road transportation should equal the cost of snigging'.

Before proceeding to 'cumbersome cut and trial optimising procedures' the balance between skidding costs, road construction costs and road haulage costs was examined.

3.4.2.1 Balance between road construction costs and snigging costs

The information collected on road construction costs was used as the basis for estimating the cost of the roads within each compartment. It has been noted that in general the standard of road construction is uniform for the construction associated with a group of compartments. By scaling off the maps shown, for example in Figure 3.1, the total length of road constructed and the proportion within the compartment boundaries can be determined. Applying average costs per unit length to the length within each compartment the total cost of road construction for each compartment can be estimated. This total cost could be expressed as a cost of road construction per unit volume, for the roads within the compartment and related to the volume harvested from the compartment.

This estimate was prepared for each compartment and the results are given later in Table 3.9, page 112.

The total skidding costs for each compartment can also be calculated as the unit rates per cubic metre for skidding are known for each compartment as is the total volume. This estimate was also prepared for each compartment and the results are also shown in Table 3.9.

The road construction costs and the snigging costs for each compartment are plotted as associated costs in Figure 3.8. In all compartments the snigging costs exceed the roading costs by very significant margins.

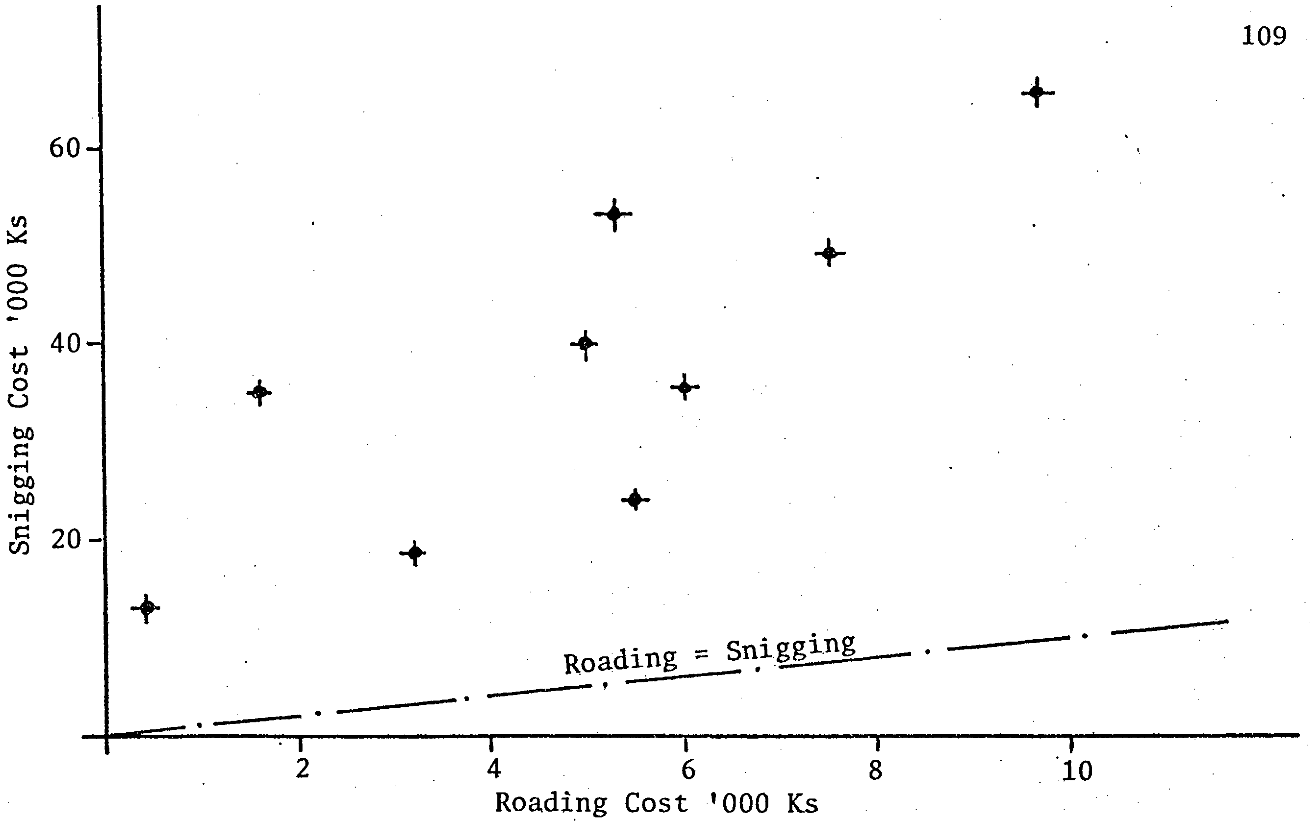


Figure 3.8 Comparison of Intra-Compartment snigging costs and road construction costs.

The disparity between the magnitude of the snigging costs and road construction costs is such that it is accepted, on the criteria that they should be equal for an optimal operation, that in all compartments the road network should be extended to reduce the skidding distances and bring the skidding costs into a better balance with the roading costs.

3.4.2.2 The balance between the cost of road construction and the cost of road haulage

The next step in this study and following the options summarized in Chapter 2 was to examine the relative costs of road construction and road haulage in terms of these costs expressed as costs per unit volume. The unit costs are also shown in Table 3.9 and plotted in Figure 3.9.

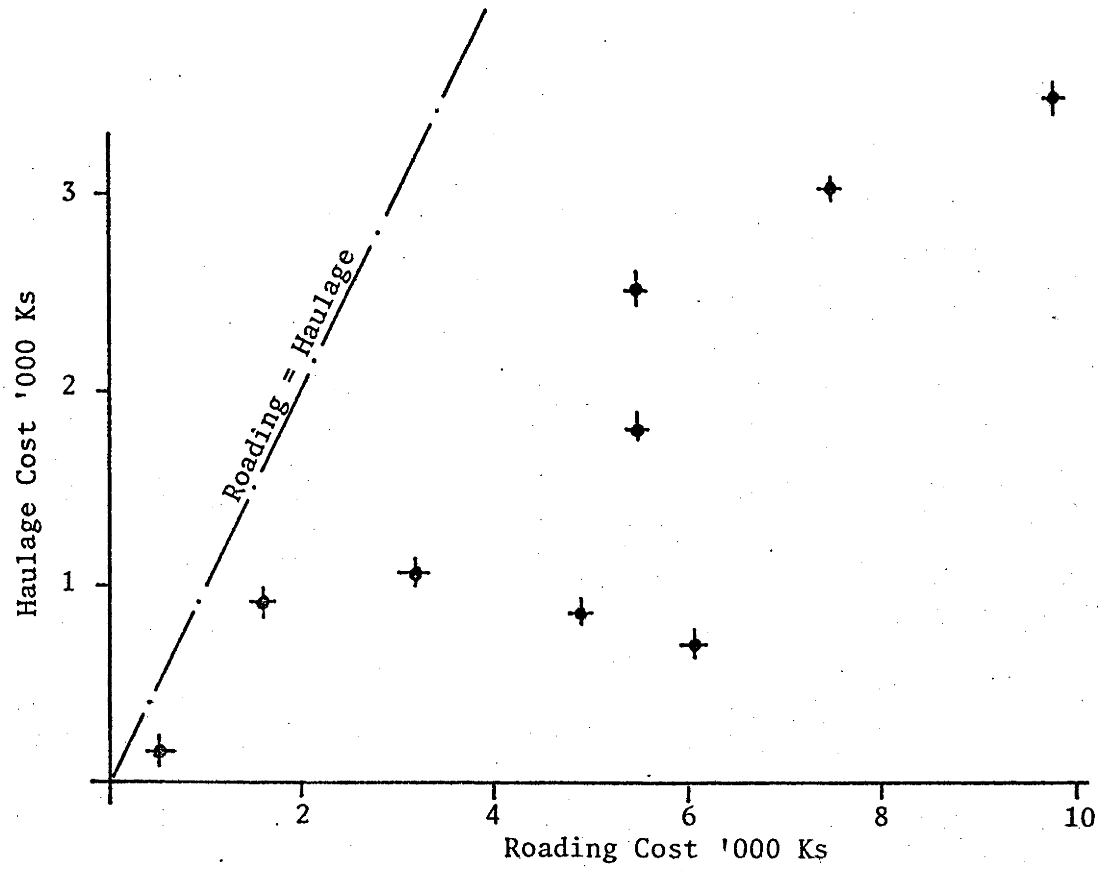


Fig. 3.9 Comparison of intra-compartment road haulage costs and road construction costs.

It is clear that the road construction and transportation costs are not in balance and that on the criteria that they should be equal it is accepted that road construction standards should be reduced and the cost of haulage per unit volume consequently increased.

It is necessary to express some reservations about this theoretically based conclusion. Field experience suggests that the standards of construction now adopted approach the minimum practicable. Reconciliation of this field based judgment with the theoretically based conclusion requires, *inter alia*, a detailed field check on road standards to ascertain that roads constructed at a lower standard would be trafficable. It may also be that the actual cost of road haulage is relatively cheap because of the very small capital outlayed in many of the existing trucks and that if more realistic costing in terms of the replacement of the existing trucks was adopted then the balance would be altered. Research to determine this requires information beyond the scope of that collected for this study and in fact beyond that readily available at the Prome Agency office.

On the basis of the data available it is concluded that there is not an optimum balance between the cost of roads and the cost of road transportation and that the standards of construction should be reviewed.

The conclusion has not been qualified in regard to the possibility that uses of the road for purposes other than wood transport would justify a higher standard than that based solely on wood transport. This would be a compelling argument in most forest road situations, for example the study by Larsson and Rydstern (1968) suggests that the transportation of labour along the road may be a higher cost than the cost of the transport of wood. However in the Prome Agency there is very little transport of labour by road and generally speaking the roads are constructed for one dry season only and effectively the roads are temporary harvesting roads.

3.4.2.3 Summary

The estimated costs for road construction, road haulage and road transport are shown together in Table 3.9. The disparity from the criteria of equality is clear.

Taken together the calculations from the available data, when placed against the criteria of equality, indicate that roads of a low standard are required to bring roading costs into balance with haulage costs and that additional roads are also required to bring roading costs into balance with snigging costs.

Table 3.9 Wood Transportation Costs: Prome Agency

Intra-Compartments

Serial No.	Compartment No.	Roading cost ks	Haulage cost ks	Skidding cost ks
1	41	5,535	1,808	53,100
2	42	9,790	3,532	65,880
3	43	6,002	714	35,915
4	44	4,895	866	40,067
5	8	5,474	2,509	23,903
6	9	1,588	906	34,930
7	10	418	188	12,900
8	11	3,218	1,098	18,790
9	12	7,522	3,021	49,725

3.4.3 Cut and Trial Procedure for Optimizing Road Construction Costs, Road Haulage Costs and Snigging Costs

The difficulties in applying theoretical procedures rigorously to an evaluation of the balance of the costs associated with wood transportation have been noted.

As an additional check to the conclusion reached that an extension of the forest road network would lead to overall economies, cut and trial procedures were adopted.

Three trials of extended roadworks were undertaken in each of nine compartments to ascertain the economies associated with extensions to the existing roads. The extended road network for each trial is shown on the maps in Appendix 3.5.

The procedure was to assume that certain road extensions, shown on the maps, were constructed. The additional cost for the roading was estimated. As a consequence of the construction of the road, skidding distances would be reduced and new estimates of synthetic skidding distances were prepared following the method described in Section 3.4.1.2. The estimated skidding distances for the actual layout and for the trials made with the extended networks are shown in Table 3.10.

Table 3.10 Estimated Skidding Distances for Actual and Trial Road Networks

Compartment No.	Estimated Skidding Distances (Synthetic)[1] metres			
	Actual Road Network	Trial I Road Network	Trial II Road Network	Trial III road Network
41	240	230	200	190
42	330	320	250	230
43	290	270	190	170
44	300	270	240	220
8	230	190	210	170
9	660	410	320	260
10	880	400	310	200
11	370	290	300	210
12	190	170	170	140

[1] Based on 100 metre grid lines

There would be reductions in the skidding costs as a consequence of the reduced distances but with the data available it is difficult to accurately estimate the savings. The actual skidding costs comprise a fixed component related to loading and a variable component related to the skidding distance. While the regression shown in Figure 3.6 suggests that the fixed cost is a very high proportion of the total skidding costs it is accepted that with the data available Figure 3.6 is not an appropriate basis for firm conclusions regarding the magnitude of the fixed and variable snigging costs relative to the total snigging costs.

In estimating the savings that would accrue from reduced snigging costs in the event that the road netowrk was extended it was assumed that the fixed costs were respectively 30%, 50%, 60% and 70%.

There would also be an increase in the haulage cost if the road network was extended, either at the same standard or a lower standard, because of the increased haul distance. The additional cost of road haulage as a consequence of an extended road network was also estimated. In the preparation of this estimate it was assumed that the road extension was at the same standard, that is the construction costs per unit length remain unchanged, and the haulage cost along the road extension would be as shown in Table 3.9 but converted to a cost per unit volume.

The results of the calculations of the costs of wood transportation associated with the extended road networks are shown in Appendix 3.6. The results for Compartment 41 are shown by way of example in Table 3.11.

In all of the trials savings are indicated from extended road networks.

TABLE 3.11 Road, Haulage and Skidding Costs for Trial Road Extensions

COMPARTMENT 41

Road Layout	Road Cost Kyats	Haulage Cost Kyats	Fixed (1) Skidding Cost %	Estimated Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	5535	1808	-	53100(2)	60443	-
Trial 1	6235	1794	0	50002	58031	2412
			30	50931	58960	1483
			50	51551	59580	863
			60	51861	59890	553
			70	52171	60200	243
Trial 2	6701	1857	0	44913	53471	6972
			30	47370	55898	4545
			50	49007	57565	2878
			60	49826	58384	2059
			70	50644	59209	1241
Trial 3	7167	1865	0	41152	50184	10259
			30	44736	53768	6675
			50	47126	56158	4285
			60	48321	57353	3090
			70	49516	58548	1895

(1) Ratios shown are fixed skidding costs as % of total skidding costs

(2) Actual recorded skidding cost

3.5 ASSESSMENT OF THE SYNTHETIC SKIDDING DISTANCES

3.5.1 Introduction

As reported synthetic skidding distances were derived for the study compartments to assist in examining for relations between costs of skidding per cubic metre and the skidding distance. The results were summarized in Table 3.2.

Deficiencies have been noted in the theoretical approach to deriving optimum spacing of roads and therefore the maximum skidding distance by the use of Equation (2) (page 70), and given below

$$a = \sqrt{\frac{y}{pt_r}} \qquad (2)$$

y = road construction costs per cubic metre
where a = the range of roads (that is ½ distance between the roads)

p = average production in cubic metres per unit area

t_r = cost per cubic metre per unit distance of transportation in the forest area which are independent of the road spacing.

Nevertheless this approach is presented in the literature, for example Sundberg (1976) and the derived synthetic distances were therefore compared with the theoretical values obtained from Equation (2).

The derived values shown in Table 3.2 are compared with theoretical values in Table 3.12.

The deficiencies in the data in respect of statistical analysis have already been noted but the information in Table 3.12 again provides support for the previous conclusion that the skidding distances in the compartments examined are too high relative to theoretical values.

Table 3.12 Comparison of derived synthetic skidding distances and theoretical maximum skidding distance.

Compartment No.	Mean Skidding Distances (metres)			
	100 metre grids [1]	Assumed actual Paths [1]	Theoretical [2]	
			Variable skidding of total skidding costs 100%	Cost as per cent of total skidding costs 50%
41	240	290	150	210
42	330	360	165	230
43	270	315	205	290
44	290	330	145	205
22	360	390	220	310
23	410	405	150	210
25	340	325	90	130
26	400	500	100	140
29	230	280	180	250
30	660	640	220	310
36	590	570	110	160
8	220	210	180	250
9	660	650	130	180
10	880	820	140	200
11	370	360	180	250
12	190	190	105	150
23	260	300	105	150

1) From Table 3.2 page 100

2) Calculated from equation (2)

3.6 REVIEW

The evaluation of the costs associated with wood transportation in the Prome Agency indicates that additional forest roads should be constructed to reduce snigging costs but that the standard of construction should be reduced.

The conclusion, based on theoretical consideration of actual costs, that road standards should be reduced cannot be readily accepted for field experience suggests that the standards of construction are already very low. On the basis of field experience they were considered, prior to undertaking this analysis, as of a minimum standard.

The standards of construction of the forest roads in the Prome Agency are not specified and in view of the findings reported a literature survey of current practice for the specification of forest road standards was undertaken. This is presented in Chapter 4.

Further discussion of the main conclusions of the evaluation is presented after considering current practice for forest road standards.

CHAPTER 4

FOREST ROAD STANDARDS

4.1 INTRODUCTION

The criteria in planning forest roads for the transport of wood that the cost of the roads should be in balance with the cost of transportation along them was discussed in Chapter 2 and used, as reported in Chapter 3, to evaluate the efficiency of some of the transportation networks in the Prome Agency. The emphasis in this criteria for planning is on the economic objective of achieving the minimum cost for wood transportation.

It is necessary of course to translate costs of roads determined by economic analysis of the overall operation into geometric and structural standards and to construction procedures, for these become the determinants of the actual cost of the constructed road and in turn the speeds of travel of the log trucks.

In this Chapter some of the current practices in relation to forest road standards and construction procedures are examined to provide a basis of common practice for the specification of design criteria.

It will be seen that in common practice design criteria for geometric and structural standards are specified and then realized by accepting the consequential costs of road construction. The design criteria can of course be changed if the costs are too high. Generally the design standards are related to topography, an adopted design speed and traffic volumes, rather than costs of transportation. It will be suggested that in the planning of forest roads for wood transportation the better approach is to relate wood transportation costs and costs of road construction and then translate these costs to design standards. It is of course a two-way relation but to specify standards independently of transport costs is more likely to lead to economic imbalance of the road construction costs and the road transportation costs.

4.2 ROAD STANDARDS

4.2.1 Vehicle Limitations

Limitations on vehicles in terms of both weight and size are legally enforced on public highways in most countries. While such regulations may not apply to forest roads it is common for trucks hauling logs over forest roads to travel on public roads for some of the distance to a mill and vehicle regulations would then apply.

Furthermore truck manufacturers usually design trucks in terms of their use on public roads rather than specially for forest roads. However there remains the option that 'off highway' vehicles can be selected for hauling along the forest roads and the road standard determined in relation to the characteristics of the truck selected.

The dimensional and weight limitations for motor vehicles in Australia are shown by way of example in Appendix 1.4.

4.2.2 Vehicle Limitations and Road Standards

The vehicle limitations restrict the size and weight of vehicles permitted on the road and thus enable some of the geometric and structural parameters associated with road design to be specified.

The dimensional limitations include width, length and height, rear overhang and axle spacing. The width limitation is required to fix the width of the road while length, overhang and axle spacing influence the width of the road on curves.

Weight limitations are particularly important in relation to the design of bridges and pavements. Where the roads are not sealed the effect on the pavement is not as critical as with sealed roads because deflections on gravelled roads can be readily repaired by a patrol grader. However the weight limitation (particularly axle load) is always important where there may be increases in the moisture content of the pavement subgrade for bearing capacity of the subgrade may be the limiting factor in trafficability without excessive damage by rutting of the running surface.

4.2.3 Design Speed

It is a common practice in road design to specify the design speed of a road while recognizing that there will be a wide range of speeds on any particular road. Where a design speed is cited it means that a vehicle can travel at that speed without being exposed to hazards arising from curtailed sight distance, inappropriately super-elevated curves, severe grades, or pavements too narrow to accommodate the design volume[1]. All of these geometric characteristics are determined in relation to the design speed of the road and it is thus a very important design parameter and with its influence on time of travel very important in relation to the cost of transport.

However in most road authority specifications, and particularly in relation to grades, the design speed is seen mainly in relation to car travel and it is not usual to construct the roads so that heavily laden vehicles can maintain the design speed on the steeper grades. Thus design speed and the related specifications may not be directly applicable to very low cost forest roads for wood transportation. Nevertheless, as

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[1] National Association of Australian State Road Authorities. Policy for Geometric Design of Rural Roads 1976. Ambassador Press, Sydney 92pp.

noted, speed of travel is a significant determinant of the cost of transportation. Given the very considerable experience and empirical data associating design speeds and construction costs it seems desirable to examine further the possibility of relating construction costs to transportation costs by the selection of an appropriate design speed. This possibility is taken up in more detail later.

4.2.4 Geometric Standards of Forest Roads

Irrespective of whether the geometry of a constructed road follows from adherence to specified road standards in design, setting out and construction or from ad hoc construction procedures the geometry of the road is a very significant factor in determining the time of travel and therefore cost of transportation. Where traffic volumes are high the savings in the total cost of transportation by reducing the travel time for each vehicle trip may become quite significant and justify expenditure on the roads to improve the road geometry.

On the other hand where traffic volumes are very low construction costs should be low and the road geometry may be related to the absolute minimum geometric standards which would allow traffic movement.

The main geometric standards are reviewed in the following sections in terms of the speed of travel and the costs of road construction.

4.2.4.1 Road gradient

The choice of gradient for forest roads depends on the danger of erosion by rainfall and the load capacity, horsepower and desired speed of the trucks in use.

The steeper the slopes the greater the risk of slipping when travelling uphill and dangerous accelerations downhill. Road maintenance costs and vehicle operating costs also increase with increasing gradients. Thus to reduce maintenance costs and improve vehicle performance grades selected should desirably be kept as low as possible. A minimum gradient of 1% is usually specified to ensure that water drains freely from the road surface and down the table drains.

On the other hand road construction costs may be increased considerably if grades are reduced below some defined maximum either because of the increased length of road to make a certain height under a ruling grade or as additional earthworks at the top of rising gradients to reduce the magnitude of the gradient.

There is general agreement in the literature in regard to the specifications of gradients but actual practice for forest roads may involve steeper gradients than are permitted by the published specifications which should perhaps be taken as recommended policies rather than practices.

In Austria, (Sedlak 1976), the maximum gradients for main roads, subsidiary roads and skidding roads are 9%, 10% and 12% respectively but maximum adverse gradients are 6%, 8% and 10% respectively. However steeper gradients of 15% and 16% are permitted in special cases at the ends of valleys where the wood production per unit area is relatively high.

In Australia the Forestry Commission of New South Wales specify road gradients in terms of the nominal design speed, as shown in Table 4.1.

Table 4.1 Gradients for Forest Roads - Forestry Commission of NSW

Nominal design speed k.p.h.	Grade (per cent)[1)] Sustained maximum	Permissible
100	4	6 (700)
80	6	8 (500)
60	6	8 (600)
50	7	8 (300)
30	8	10 (500)
		12½(150)
20	10	

1) Figures in brackets show the lengths in metres for which the permissible grade is allowed

Stodart (1971) under classification of plantation roads as Plantation Access, Land Access and Compartment Access and Compartment Trails suggested maximum gradients of 7%, 8%, 10% and 12% respectively.

In Canada the maximum favourable grades suggested by Adamovich and Webster (1968) for forest roads range from 10% to 14% with maximum adverse grades from 6% to 12%.

Anon. (1976) stated that in India the gradients of access roads and subsidiary roads are 4% and 5% respectively. In Mexico, the gradients are specified as 5%, 7% and 8% for principal, secondary and access roads respectively. In Nepal (Anon. 1976) the gradients are specified as 4%, 5% and 6.5% for first, second and third class roads respectively.

In Turkey (Anon. 1976) the gradients of forest roads in mountainous regions where extraction has not been mechanized vary from 8% to 12%. Class 1 roads can have 8% and class IV 12%, while the gradient for class II and class III is 10%.

In Oregon in the United States of America the Bureau of Land Management (Pearce, 1973) states that the maximum favourable grades are 8% and 10% for class I and II roads but with the maximum adverse grades 6% and 7% respectively.

There is a dearth of recent literature regarding the performance with respect to grade of logging trucks on forest roads. Beath (1976) derived a gradient model for logging trucks which is shown as Appendix 4.1. Beath concluded that in respect of vehicle performance relatively steep maximum grades would be most economic for forest roads designed for hauling logs.

Byrne, Nelson and Coogins (1960) using 1957 data presented graphs which showed the relation between travel time and gradient for logging trucks. The horsepower, ratio of effective horsepower to rated horsepower at various elevations and the gross vehicle weight are the vehicle parameters in the relationship and graphs are presented for loaded and empty trucks on asphalt paved roads, compacted gravel roads and dirt roads. The range of grades are from +12% to -16%. Examples of the graphs are shown as Appendices 4.2 and 4.3.

The National Association of Australian State Road Authorities commissioned a study on performance and operational characteristics of vehicles. In connection with that study performance-prediction graphs were generated which showed the estimated power requirements for a given road speed on grades up to 7%. Examples of the graphs are shown in Appendices 4.4 and 4.5. The shape of the performance curves changes as the grade increases. At very low grades the predominant force to be overcome is the wind resistance which is very dependent on speed. The resolved part of the mass in the direction of the grade becomes the predominant part of the total drag at high grades and this is independent of speed. The maximum grade in this study was 7%.

4.2.4.2 Width

The type and width of vehicles, the volume of traffic and the desirable speed are the main factors influencing the width of the road.

As with the specification of other road geometry parameters the usual practice, for both public and forest roads, is for width to be specified in terms of a road classification. Current practice for the specification of the width of forest roads is indicated below.

In Canada McGraw (1963) states that the widths of Class A, B and C roads are 7.9, 6.7 and 5.5 metres respectively from ditch to ditch. In India (Anon. 1976) the width of carriageway is specified as 2.5 metres for subsidiary forest roads, and 3.5 to 4 metres for access roads. In Iran, the widths are 6.5 to 7.3, 4.5 to 5.0 and 4.0 for main roads, class I roads and class II roads respectively. In Mexico (Anon. 1976) road widths are 4.5, 4.2 and 3.0 metres for first, second and third class roads respectively. In Turkey in mountainous regions road bed widths are 7, 6, 4 and 3 metres for class I, II, III and IV roads respectively. In Oregon in the United States of America the Bureau of Land Management specifies 7.38, 6.16 and 3.66 metres respectively for surface widths of class I, II and III respectively.

Heinrich (1976) recommends that for forest roads in tropical high forest the carriageway should be 7 to 10 metres for access roads, 6 to 8 metres for main forest roads and 3.5 to 4.5 metres for skidding roads, but goes on to suggest that in steep and difficult terrain conditions the widths could be reduced considerably. Stodart (1971) suggests, for plantation roads in Australia, formation widths of 5.5 m for compartment trails, 6.1 m for compartment access, 7.3 m for land access and 8.6 m for plantation access roads.

4.2.4.3 Sight distance

Sight distance is the distance at which a driver of a vehicle can see an object of specified height on the road ahead of him, assuming adequate light and visual acuity and clear atmospheric conditions. It may be necessary of course to be able to stop the vehicle over the sight distance. On a single width road sight distances on curves under 30.5 m (100') radius become seriously deficient. Sight distances that should be provided depend on design speed, type of road, locality and particularly the coefficient of friction between the road and the pavement.

Practice in regard to sight distances on forest roads is indicated by the following. In Canada (McGraw, 1963) sight distances for road classes are as given in Table 4.2.

Table 4.2 Sight distances in Canada

Road class	Travel speed km/h Loaded	Empty	Sight distance on curves (metre)
A	32	56	49
B	16	28.8	37
C	11.2	17.6	24

In the University of British Columbia Research Forest, sight distances are established with regard to design speed for horizontal and vertical curves as shown in Table 4.3 (Adamovich and Webster, 1968).

Table 4.3 Sight distances in British Columbia Research Forest

Design speed (km/h)	Horizontal sight distance (metre)	Sight distance for vertical curve (metre)
16	18	31
24	31	61
40	49	76
56	76	92

In Norway sight distances are specified in relation to grade and vehicle speed (Skaar, 1972). A reaction time of 2 seconds and a friction coefficient of 350 kg per tonne are assumed. The coefficient of friction of a moist and uneven gravelled forest road varies from 200-400 kg per tonne over the range of conditions in Norway, which include wet snow.

Sight distances are specified as in Table 4.4.

Table 4.4 Sight distances in relation to speed and grade in Norway (metres)

Grade %	Speed in km per hour 20	30	40	50	60
-10	16	26	40	57	79
- 7	15	25	38	54	74
- 5	15	24	37	52	69
0	14	23	35	48	64
5	13	22	33	45	59
10	13	22	32	43	57

Stodart (1971) suggests sight distances in terms of a classification of plantation roads, as shown in Table 4.5.

Table 4.5 Sight distances in Australian Plantations

Road classes	Design speed	Sight distance (metre)
Compartment trails	24 km/h	15
Compartment access	32 "	23
Land access	48 "	46
Plantation access	64 "	61

The desirable and minimum sight distances for various design speeds on rural roads in Australia are given in Table 4.6. It assumes a driver eye height of 1.38 m (4'6") and an obstruction on the road 0.1 m (4") high.

Table 4.6 Sight distances for rural roads in Australia

Design speed (km/h)	Desirable sight distances (metres)	Minimum sight distances (metres)
48	92	61
64	122	84
80	152	107

Source: National Association of Australian State Road Authorities (1964)

Sight distances on bituminous rural roads in Australia are shown in Table 4.7.

Table 4.7 Sight distances on bituminous roads in Australia

Design speed (km/h)	Stopping sight distances (metre)	Intermediate S.D. sight distances (metre)	(metre)	Overtaking sight distance (metre)
40	40	80	55	150
50	60	120	85	200
60	80	160	110	300
70	100	200	140	350
80	120	240	170	450
90	140	280	195	600
100	170	340	240	750
110	210	420	290	900
120	250	500	350	1100
130	300	600	420	1400
Ht.of eye	1.15 m	1.15 m	1.15 m	1.15 m
" " object	0.20 m	1.15 m	0.20 m	1.15 m

Source: National Association of Australian State Road Authorities (1976)

In Oregon State the sight distances on vertical curves are 112 m, 92 m and 76 m for class I, II and III roads respectively.

4.2.4.4 Widening

A vehicle travelling on a curve occupies a greater width of the road than it does on a straight road because the rear wheels track inside the front wheels at slow speeds and outside at high speeds. Therefore it is necessary to widen the width of a road on curves to maintain the same lateral clearance between vehicles as on a straight section. The required amount of widening depends on the radius of curve, on the width of land on straight road and on the dimensions of vehicles.

The literature review on forest road standards suggests that the specification of widening on forest roads is not as common as grade, width and curvature.

In Canada Adamovich and Webster (1968) state that widening on curves in the University of British Columbia Research Forest is 0.3 m for each 10^{o} of curvature. In the United Kingdom (MacMillen, 1965) widening of roads associated with afforestation and heavy thinning should be as below.

Table 4.8 Road widening United Kingdom

Radius (metres)	Widening (metres)
30.58	3.05
27.52	3.35
13.75-18.34	4.88

Stodart (1971) for plantation roads in Australia suggests widening in terms of design speed and the minimum radius as shown in Table 4.9.

Table 4.9 Widening for plantation roads in Australia

Design speed (km/h)	Desirable minimum radius (metres)	Absolute minimum radius (metres)	Widening	
			Desirable (metres)	Absolute (metres)
24	22.9	15.3	1.52	2.45
32	30.6	22.9	0.91	1.22
48	91.7	45.8	0.61	1.22
64	152.9	61.2	0.00	0.00

In Australia the National Association of State Road Authorities has adopted the widths shown in Table 4.10 for widening around horizontal curves on rural roads.

Table 4.10 Widening for rural roads in Australia

Curve radius (metres)	Amount of widening (metres) for sealed pavement with a width on straight of		
	5.6 m	6.2 m	6.8 m
Below 60	1.8	1.5	1.2
60 - 120	1.5	1.2	0.9
120 - 240	1.2	0.9	0.6
240 - 750	0.9	0.6	0.0
750 - 1500	0.6	0.0	0.0
Over 1500	0.0	0.0	0.0

Source: National Association of Australian State Road Authorities (1976)

The general rule adopted in the Bureau of Land Management of Oregon State is that the required widening value can be obtained by dividing 400 by the radius of curve in feet.

4.2.4.5 Horizontal curvature

Horizontal curvature is measured by the radius of the curve and usually a minimum radius of curve is specified in relation to a design speed for the road. The sight distances to be provided also influence the choice of the radius of the curve. The practical absolute minimum radius of a horizontal curve is influenced by the maximum turning radius of the vehicles using the road. Most commercial vehicles have a turning radius of less than 14 metres.

Current practice for the specification of minimum radii for forest roads is indicated below. In Austria (Anon. 1976) the minimum radius on a main road should be 14 to 16 metres and for a subsidiary road 12 metres. In India (Anon. 1976) the minimum radius for an access road is 16.5 m and for a subsidiary road 14 m. In Nepal (Anon. 1976) the specification is 18.3 m for first class roads, 15.3 m for second class and 12.2 m for third class roads. In Turkey the minimum radius of curve on forest roads is 50 m, 35 m, 30 m and 20 m for Class I, II, III and IV forest roads respectively.

Heinrich (1976) suggests that for forest roads in tropical high forest the minimum radius should be 50, 30 and 20 m for access roads, main roads and secondary roads respectively. Stodart (1971) suggests, for plantation roads in Australia, minimum radii ranging from 15.3 m to 153 m based on design speeds.

4.3 REVIEW

The analysis of the balance between the road construction costs, road transportation costs and snigging costs, reported in Chapter 3, indicated inter alia that road standards in the compartments studied may be too high. Reservations were expressed in regard to this theoretically based result and a literature survey of the specification of road geometry was undertaken to provide a basis for a comparative assessment of the road standards in the study compartments.

While providing interesting and useful background information, the literature survey does not provide a basis for comparative assessment of the low cost roads in the study compartments. The main reason is that, with the exceptions enumerated below, the literature on forest road standards, and particularly that in relation to low cost roads, is deficient in respect of

(1) Volume and type of traffic in relation to the specified standards

(2) Vehicle performance in relation to the specified standards

(3) Road construction and road transportation costs in relation to the specified standards.

The exceptions cited are Byrne, Nelson and Coogins (1960), Beath (1976) and National Association of Australian State Road Authorities (1976). However these studies reported results of vehicle performance for roads of much higher standard than those under consideration in this study.

A second reason for the information extracted from the literature not being directly useful for a comparative assessment of the standard of the roads in the compartments under study is that they are in general of a standard well below the standards reported in the literature.

The geometric standards reviewed were -

(1) Road gradient

(2) Width

(3) Sight distance

(4) Widening

(5) Horizontal curvature.

As noted previously there is no specification of geometric standards for compartment roads in the Prome Agency and it is considered unlikely that savings in construction costs could be obtained by reductions in the standards, ad hoc as they are, of sight distance, widening and horizontal curvature.

It is suggested that there may be savings from construction costs incurred with existing practices by reductions in the standards of construction with respect to grading and width. Field work related specifically to the evaluation of these two standards is desirable but recommendations are made in Chapter 5 regarding the specification of grades and widths for compartment roads in the Prome Agency.

CHAPTER 5

REVIEW AND CONCLUSIONS

5.1 WOOD TRANSPORTATION IN BURMA

The commercial extraction of teak began early in the nineteenth century. In 1860 pressure increased to allow private enterprise to export teak on a larger scale. Private companies produced teak logs and sawn timber for export markets until World War II. The Forest Department now has responsibilities for wood growing and the Timber Corporation for felling, logging, transportation, milling and marketing.

Floating and rafting of the logs is an important operation in wood transport and the only practical method of delivery to the ports from some forests. Floating and rafting require the teak logs to be dried and girdling of teak trees three years before felling to enable water transport is common practice.

Elephants and buffaloes are the main means of snigging logs from the stumps although some mechanical equipment, first introduced in 1954-55, is used.

Export of forest products, still mostly teak, has always been a major source of foreign exchange earnings and on occasions the export commitments have not been met because of transportation problems. For example, between 1969 and 1972 only 50% of the contracted log sales and 68% of the contracted conversions were actually shipped. It would help a pressing shortage if the forestry sector could earn more foreign exchange.

Production of teak and hardwoods has not increased significantly from year to year but the population has and per capita consumption has therefore decreased. The increasing population calls for a steadily increasing volume of construction timber if housing standards are to be maintained.

The amount of teak which could be harvested annually in Burma without affecting sustained yields is about 80,000 m^3 greater than the volume extracted and there is at present, as a consequence of transportation problems, some 700,000 ripe girdled teak trees standing without increment. Marketable hardwood species are also left in the forest, for the harvested volumes are lower than the annual allowable cut.

The limitations of the existing transport system presents perhaps the most significant difficulty in rapidly expanding the delivery to mills of both teak and hardwood.

Road transportation has several advantages as a complementary method to water transportation. Not all the teak forests can be economically harvested based on water transportation for, while very extensive, suitable waterways are limiting in some places. Girdling of teak trees to air dry the log to achieve flotation is not necessary, hardwood species that cannot be floated can be transported to mills and the joint production of teak and hardwood becomes possible. Losses, by theft etc., during floating and rafting can also be avoided.

There are many options that could be examined in determining the most appropriate way to improve the wood transportation system now in operation. Procurement of imported goods often presents insuperable obstacles and many machines are already idle because of lack of parts and therefore increased efficiency of the existing operations, rather than increased mechanization of the operations, should be one of the first options examined; particularly in the case of teak production as increased efficiencies may be sufficient for, as stated earlier, annual production is only 10-15% below the sustained yield.

It is clear that for improved utilization of the extensive hardwood forests some form of land transport must be investigated because they are non-floatable and in some cases waterways are not available close enough to the stump.

This study therefore examined the balance between the magnitude of the efforts allocated to road construction, snigging and road transport from the point of view of optimizing the allocation of resources between these three related operations.

5.2 STUDY METHODS

There are many approaches to an investigation aimed at ensuring the lowest overall delivered cost of wood. Proadly they could range from detailed work study of a single operation, for example felling teak trees, to a planning study at a national level. The approach in this study was influenced considerably by the intentions of the Timber Corporation in providing the opportunity to take up a Colombo Plan Scholarship, for they wished one of their staff to study in the area of forest roads.

This study therefore began with an orientation to the planning and design of forest roads.

Many procedures for the planning and design of forest roads have as their basis policies for the selection of geometric standards of construction. The literature survey associated with this study suggested that analytical procedures may provide a more efficient approach to the formulation of policies for they have a theoretical basis.

It was concluded from study of the literature that the following procedures may be appropriate.

1. Methods after Larsson and Rydstern (1968) provided that the necessary relations can be determined and that the actual layout conforms to the assumed schematic layout.

2. That the cost of road construction for any length, expressed as a cost per cubic metre of wood transported along the length, should equal the cost of wood transportation per cubic metre when other uses of the road can be disregarded.
3. Cumbe-some cut and trial optimising procedures.
4. Approximations to optimal solutions by determining the spacing of roads so that the road costs are in balance with the variable snigging cost.
5. The working rule suggested by several writers that the cost of the road should equal the cost of transportation along the road and in turn equal the cost of snigging to the length of road.

Direct application of the Larsson and Rydstern (op cit) method to evaluation of an existing logging network requires expression in mathematical terms of the relationships between the cost of snigging and the distance snigged and between the cost of road construction and the cost of road transportation, and also that the layout of the road network can be represented in a geometric form which enables application of the relationships.

The Prome Agency was chosen as an area which would enable case studies of the feasibility of using analytical procedures, to evaluate the efficiency of the transport networks that had been constructed for the logging of compartments in the Agency.

Examination of some of the networks in the Agency indicated that the existing networks could be represented in a form which would enable application of the formulation by Larsson and Rydstern (1968).

Synthetic skidding distances were derived to examine the relationship between the costs of snigging per unit volume and the skidding distances. Figure 3.6, below as Figure 5.1, shows the relationship as determined by a linear regression.

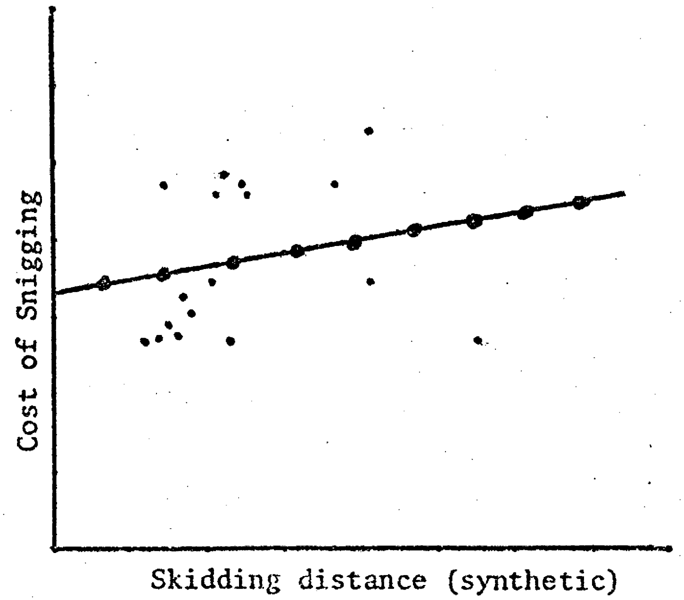


Figure 5.1 (and Figure 3.6) Relationship between cost of snigging and skidding distance (synthetic)

For other reasons discussed below it is not possible to rigorously apply the theoretical methods and because of this,but also because it was not feasible to obtain additional cost data, a more detailed examination of Figure 5.1, although a most important relation in the context of this study, was not undertaken. However several points can be noted regarding the regression.

1. The intercept of the regression line on the axis representing the cost of snigging per unit volume indicates the fixed cost of snigging. It is a high proportion of the actual snigging costs. The reasons for this are not clear and require detailed field studies.

   Accepting the indications of the regression line then snigging costs per unit volume are not very sensitive to increases in skidding distance. It is suggested later that this may be one reason why long skidding distances have been accepted in planning road networks. Here it must be said that accounting and tendering procedures may influence the unit costs. Field studies to elucidate by work study methods the determinants of the relativity between the fixed and variable costs are most desirable.

2. Large variations in skidding costs are to be expected given the variations in terrain and working conditions. Nevertheless the range in the costs is extraordinary. The compartments are all in the same area, elephants were used for the skidding and there was no remarkable change in the piece size between compartments and yet in one compartment average skidding cost per unit length is about 60% of that in another in which the average skidding distance is only one fourth as long.

3. There are also unexpectedly large differences between the estimated skidding distances for each compartment. This arises to some extent from the design of the road network but it may well be that the prices tendered for snigging, and presumably based on the field estimated skidding distance, bear no relation to the actual snigging distances involved.

The third requirement of the Larsson and Rydstern (op cit) formulation is for a mathematical relationship between road construction costs and the cost of road haulage per cubic metre. It was not possible to develop a relationship for this study although there were indications that this may be because of lack of data. That is to say a relationship may be established if sufficient data was obtained.

It was therefore accepted that further evaluation by way of a rigorous mathematical approach was not practicable with the data available.

Larsson and Rydstern (1968) found that the relation between road construction costs and road haulage costs was of an inverse form. In that case, and as discussed in Appendix 5.1, the minimum cost for the sum of road haulage and road construction occurs when the two costs are equal. This criteria was used to examine the balance between road construction costs and road haulage costs.

It was found that the two costs, for the road construction and for the road haulage, were not in balance for the compartments examined and it was concluded that road standards should be reduced with a consequential increase in haulage costs.

While noting that the theoretical basis is not as sound, the criteria of balancing the costs of snigging with the costs of road construction was also used to evaluate the costs incurred in logging the compartments at Prome. The snigging costs are remarkably high with respect to the road construction costs and it was concluded on the basis of this criteria that the road network should be extended.

This latter conclusion was substantiated by making trials in eight compartments of logging with assumed extended road networks. In all cases and even assuming that the fixed costs of snigging are a high proportion (70%) of the total snigging costs the results indicated that it would be more economic, that is the delivered cost of wood would be reduced, to extend the road network in the compartment.

Thus the results of the study suggest that in general lower costs for wood transportation would follow from extending the road networks and reducing road standards.

5.3 FOREST ROAD STANDARDS

First hand observations of the roads in the Prome Agency were that the standards of construction were minimal and the result from the analysis of the data that the standards of construction should be reduced to obtain a more economic balance between construction costs and haulage costs was surprising although it was recognized that traffic volumes and speeds were quite low.

While geometric standards are not specified for the forest roads in the Prome Agency they are for many countries and a literature review of current practice for the specification of forest roads was undertaken. The minimum standards specified in other countries seem high relative to the observations made while the author was attached to the Prome Agency. It was suggested in view of two relatively unusual features of the forest roads, namely, that they are for temporary dry season use only and that the trucks using them are of low power, that two geometric standards, grade and width, may be of importance in achieving savings in construction costs.

While steep grades would in some situations reduce the length of road required to provide road access to within some 'maximum skidding distance' they may, if excessive, preclude use by fully loaded trucks. However the road extensions which would be practical if the general conclusions of this study were acted upon would be, in many places, extensions up gullies. Log trucks would not then travel them with adverse grades.

The literature suggests maximum grades of up to 14% on forest roads. Safety considerations may dictate that this is too high for narrow roads but at least field performance of trucks on grades as steep as this should be obtained, and it would be recommended for field trial that while the maximum grade for short spur roads constructed to reduce skidding distances should be 14% the maximum adverse grade allowed should be 12% and for only short distances, say 100 metres.

The width of road may be one geometric parameter which could be reduced in the Prome Agency. Many spur roads can be constructed to last for only one dry season. Table drains would for many of these roads be unnecessary, and given that there will only be a few trucks operating on them, it may even be practicable to arrange loading so that trucks would not be required to pass each other except in the case of breakdowns; it is concluded that the minimum practical width should be adopted. Minimum practical width must be determined in relation to truck width and with maximum truck width of 2.6 metres it is recommended that a formation width of 3.5 metres be adotped for all one-season only roads but with passing places provided when it will be necessary for loaded and unloaded trucks to move along the same road. Truck widths less than 2.6 metres are still common in Burma and for trucks of less than the maximum manufactured width of 2.6 metres, road widths 0.9 metres wider than the trucks should be adopted.

5.4 SUMMARY AND CONCLUSIONS

This study suggests that it would be feasible to undertake a rigorous economic evaluation of the design of the wood transportation road systems in some areas of Burma but that the collection of more accurate and detailed data to that available for this study would be required.

The results of investigations by means of analytical procedures of the balance between road construction costs, snigging costs and road haulage costs in some logged compartments invite the conclusion that savings would have accrued from an extension of the road network and lower standards of construction.

The conclusion was substantiated by making trials with assumed road extensions and estimating what the costs of extraction would have been. In all nine compartments in which trials were made savings from extension of the road network were indicated.

It is recommended that in planning and designing the extraction of wood by road each valley leading away from a road be examined using the best obtainable cost data to determine if the construction of a spur road would produce cost savings.

APPENDIX 1.1

BURMA'S MARKETABLE HARDWOODS* OTHER THAN TEAK

Group	Average Percent Extracted from 1964-69	Burmese Name	Botanical Name		Royalty K/LT	US$ m^3(r)
I	19	Pyinkado	*Xylia dolabriformis*	Benth.)		
	1	Padauk	*Pterocarpus macrocarpus*	Kurz.)		
	1	(Thingan	*Hopea odorata*	Roxb.)	24.00	2.76
		(Thingan-net	*Hopea helferi*	Brandis)		
II	2	Thitya	*Shorea oblongifolia*	Thw.)		
	2	Ingyin	*Pentacme siamensis*	Kurz.)		
	1	Kokko	*Albizzia spp.*	Benth.)		
		(Thitka	*Pentace burmanica*	Kurz.)	12.00	1.38
		(Thitsho	*Pentace griffithii*	King.)		
	1	(Thitkado	*Cedrela toona*	Roxb.)		
		(Sagawa	*Michelia champaca*	Linn.)		
III	23	In	*Dipterocarpus tuberculatus*	Roxb.)		
	21	Kanyin	*Dipterocarpus spp.*	)		
	1	Pyinma	*Lagerstromia speciosa*	Pers.)		
	1	Thadi	*Protium serratum*	Engler.)		
		(Yinma	*Chukrasia spp.*	Juss.)	6.00	0.69
	1	(Yemane	*Gmelina arborea*	Roxb.)		
		(Hnaw	*Adina cordifolia*	Hock)		
		(Binga	*Mitragyna rotundifolia*	O.Ktze)		
IV	3	Match wood	*Salmalia spp.*	Shott & Endl.)		
			Anthocephalus cadamba	Mig.)		
				)		
V	1	Taungthayet	*Swintonia floribunda*	Griff.)		
	1	Tawthayet	*Mangifera caloneura*	Kurz.)		
	1	Taukkyan	*Terminalia tomentosa*	WA)	4.00	0.46
		(Mani-awga	*Carallia brachiata* (Lour.)	Merr.)		
		(Yindaik	*Dalbergia cultrata*	Grah.)		
	1	(Thinwin	*Millettina pendula*	Benth.)		
		(Tamalan	*Dalbergia oliveri*	Gamble.)		
		(Sandawa	*Cordia fragrantissima*	Kurz.)		
	19	Others				
	100	Total				

* From a total of some 2,000 indigenous tree species

Source: Forest Department, Burma. 1974.

APPENDIX 1.2

Sheet 1 of 4

LIST OF SPECIES COMMONLY FOUND IN THE VARIOUS FOREST TYPES OF BURMA

Burmese Name	Botanical Name
	Tropical Wet Evergreen
Tree Species	
Aukchinsa	Diospyros chretioides Wall
Gangaw	Mesua ferrea Linn.
Kanaso	Baccaurea sapida Muell.
Kanyin	Dipterocarpus spp.
Karawe	Cinnamomum inunctum Meissn.
Kaunghmu	Anisoptera scaphula (Roxb.) Pierre
Kyilan	Shorea assamica Dyer.
Myauklok	Artocarpus lakoocha Roxb.
Sagawa	Michelia champaca Linn.
Taungpein	Artocarpus calophyllya Kurz.
Taungthayet	Swintonia floribunda Griff.
Tawthayet	Mangifera caloneura Kurz.
Thabyegyi	Eugenia grandis Wight.
Thingadu	Parashorea stellata Kurz.
Thingan	Hopea odorata Roxb.
Thitka	Pentace burmanica Kurz.
Thitsho	Pentace griffithii King
Yinma	Chukrasia tabularis A. Juss.
Bamboos	
Tinway	Cephalostachyum pergracile Munro
Wabo or Kyalo	Dendrocalamus brandisii Kurz.
Wabomyetsangye	Dendrocalamus hamiltonii Nees. ex. Arn.
Wanwe	Oxytenanthera albo-ciliata Munro
Wapyugyi	Gigantochloa macrostachaya Kurz.
Wathabut	Bambusa marginata Munro
	Tropical Semi-Evergreen
Tree Species	
Baing	Tetrameles nudflora R. Br.
Bambwe	Careya arborea Roxb.
Didu	Salmalia insignis Schott and Endl.
Gwe	Spondias pinnata (Linn.) Kurz.
Gyo	Schleichera oleosa (Lour.) Merr.
Kalaw	Hydnocarpus kurzii (King) Warburg
Kanyin	Dipterocarpus spp.
Letkok	Pterygota alata (Roxb.) R. Br.
Letpan	Salmalia malabarica Schoot and Endl.
Myaukchaw	Homalium tomentosum Benth.

LIST OF SPECIES COMMONLY FOUND IN THE

VARIOUS FOREST TYPES OF BURMA

Burmese Name	Botanical Name
Pyinkado	Xylia dolabriformis Benth.
Pyinma	Lagerstroemia speciosa (Linn.) Pers.
Sit	Albizzia procera Benth.
Taukyan	Terminalia tomentosa W. and A.
Taungpeinne	Artocarpus chaplasha Roxb.
Teak or Kyun	Tectona grandis Linn. f.
Thabaung	Calamus longisetus Griff.
Thabye	Eugenia spp.
Yemane	Gmelina arborea Roxb.
Bamboos	
Kyathaungwa	Bambusa polymorpha Munro
Tinwa	Cephalostachyum pergracile Munro
Wabomyetsangye	Dendrocalamus hamiltonii Nees and Arn.
Wapyu	Dendrocalamus membranaceus Munro
	Moist Upper Mixed Deciduous
Tree Species	
Binga	Mitragyna rotundifolia O. Ktze.
Didu	Salmalia insignis Schott and Endl.
Myaukchaw	Homalium tomentosum Benth.
Nabe	Lannea grandis Eng.
Padauk	Pterocarpus macrocarpus Kurz.
Pyinkado	Xylia dolabriformis Benth.
Pyinma	Lagerstroemia speciosa Pers.
Teak or Kyun	Tectona gradis Linn. f.
Yemane	Gmelina arborea Roxb.
Bamboos	
Kyathaungwa	Bambusa polymorpha Munro
Tinwa	Cephalostachyum pergracile Munro
Wabomyetsangye	Dendrocalamus hamiltonii Nees ex Arn.
	Dry Upper Mixed Deciduous
Tree Species	
Mnaw	Adina cordifolia Hook. f.
In	Dipterocarpus tuberculatus Rosb.
Ingyin	Pentacme siamensis (Miq.) Kurz.
Lein	Terminalia pyrifolia Kurz.
Padauk	Pterocarpus macrocarpus Kurz.
Panga	Terminalia chebula Retz.
Pyinkado	Xylia dolabriformis Benth.
Taukkyan	Terminalia tomentosa W. and A.
Teak or Kyun	Tectona grandis Linn. f.
Thitya	Shorea oblongifolia Thw.

APPENDIX 1.2

Sheet 3 of 4

LIST OF SPECIES COMMONLY FOUND IN THE VARIOUS FOREST TYPES OF BURMA

Burmese Name	Botanical Name
Bamboos	
Kyathaungwa	Bambusa polymorpha Munro
Thaikwa	Bambusa tulda Roxb.
Thanawa	Tyrsostachys oliveri Gamble
Tinwa	Cephalostachyum pergracile Munro
Myinwa	Dendrocalamus strictus Nees.
	Lower Mixed Deciduous
Tree Species	
Leza	Lagerstroemia tomentosa Presl.
Myaukchaw	Homalium tomentosum Benth.
Pyinkado	Xylia dolabriformis Benth.
Pyinma	Lagerstroemia speciosa (Linn.) Pers.
Sit	Albizzia procera Benth.
Taukkyan	Terminalia tomentosa W. and A.
Teak or Kyun	Tectona grandis Linn. f.
Yon	Anogeissus acuminata Wall.
Zinbyun	Dillenia pentagyna Roxb.
	Deciduous Dipterocarp or Indaing Forests
Tree Species	
In	Diptercarpus tuberculatus Roxb.
Ingyin	Pentacme siamensis (Miq.) Kurz.
Thitsi	Melanorrhoe usitata Wall.
Thitya	Shorea oblongifolia Thw.
	Dry Forests
Tree Species	
Dahat	Tectona hamiltoniana Wall.
Sha	Acacia catechu Willd.
Tanaung	Acacia leucophloea Willd.
Te	Diespyros burmanica Kurz.
Than	Terminalia oliveri Brandis
Bamboos	
Myinwa	Dendrocalamus strictus Nees

APPENDIX 1.2
Sheet 4 of 4

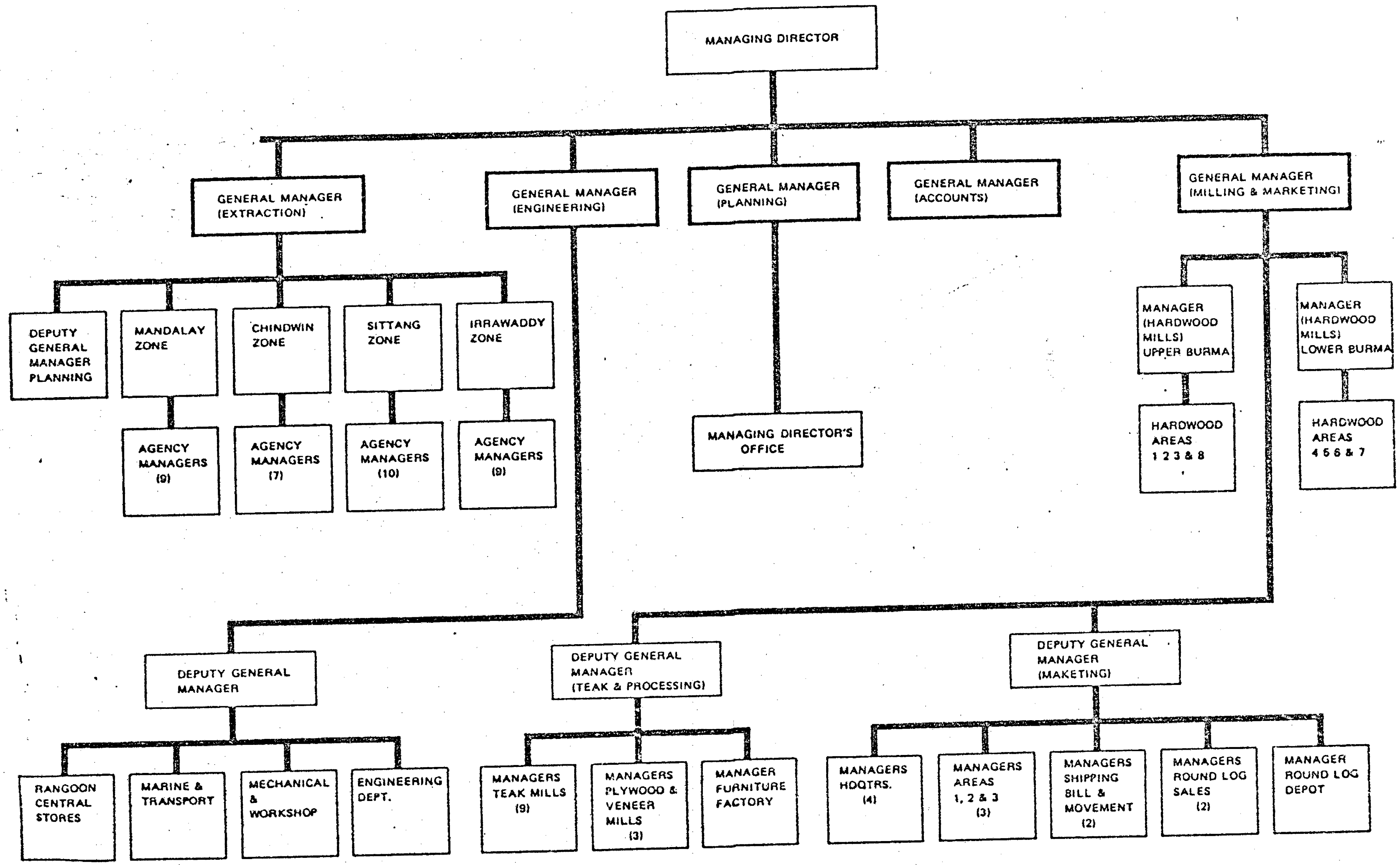
LIST OF SPECIES COMMONLY FOUND IN THE

VARIOUS FOREST TYPES OF BURMA

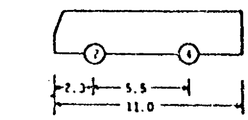
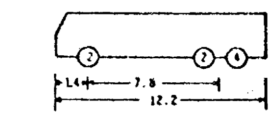
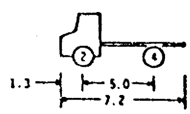
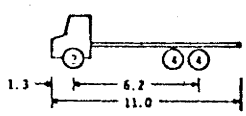
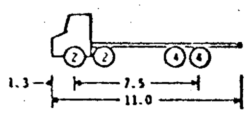
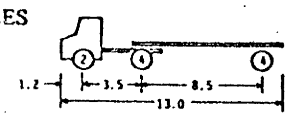
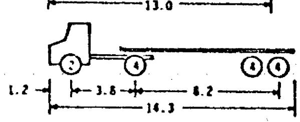
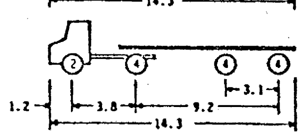
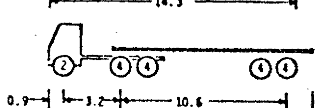
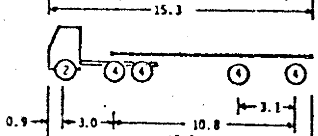
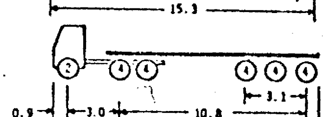
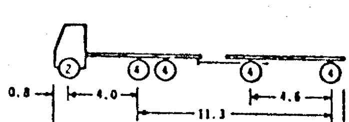
Burmese Name	Botanical Name
	Hill Forests
Tree Species	
Laukya	Schima wallichii Choisy
Maibau	Alnus nepalensis Don.
Thitcha	Castanopsis spp.
Thite	Quercus spp.
Tinshu	Pinus merkusii Jungh.
Tinshu	Pinus kesiya Royle ex Gordon
	Tidal Forest
Tree Species	
Baingdaung	Ceriops roxburghiana Arn.
Byu	Rhizophora mucronata Lam.
Hnit	Brugucera parviflora W. and A.
Kanazo	Heritiera fomes Buch.
Kaya	Acanthus ilicifolius Linn.
Kyana	Xylocarpus moluccensis Lam.
Madama	Bruguiere caryophylloides Blume.
Tree Species	
Kabwe	Casuarina equisetifolia Forst.
Kathit	Erythrina indica Lam.
Myatya	Grewia microcos Linn.
Ponnyet	Calophyllum inophyllum Linn.
Swedaw	Thespesia populnea Corr.
Thabye	Eugenia spp.
Thinwin-pyu	Pongarnia pinnata Linn.
	Swamp Forest
Tree Species	
Pyinma	Lagerstroemia speciosa (Linn.) Pers.
Tawthayet	Mangifera caloneura Kurz.
Thitni	Amoora cucullata Roxb.

APPENDIX 1.3

TIMBER CORPORATION
ORGANIZATION CHART



STATUTORY LOAD LIMITS ON AUSTRALIAN STATE AND TERRITORY ROADS AT NOVEMBER 1977

TYPICAL VEHICLES	Extreme Axle Spacing (metres)	MAXIMUM EFFECTIVE GROSS VEHICLE OR COMBINATION MASS (tonnes)						
		NSW	VIC	QLD	SA	WA	TAS*	NT
SES								
axle 	5.5	13.2 (14.5)	12.8 (13.3)	12.7 (14.9)	14.8 (14.7)	12.7 (13.4)	12.8 -	14.4 (15.8)
axle 	8.4	16.6 (17.9)	15.8 (16.3)	15.8 (18.3)	23.0 (22.0)	15.7 (16.6)	16.4 -	19.8 (21.8)
GID TRUCKS								
axle 	5.0	13.2 (14.5)	12.8 (13.3)	12.7 (14.9)	14.8 (14.7)	12.7 (13.4)	12.8 -	14.4 (15.8)
axle 	6.0	18.8 (20.1)	17.9 (18.4)	17.8 (20.5)	23.0 (22.9)	17.7 (22.0)	18.9 -	21.4 (23.5)
axle 	7.5	23.6 (24.1)	22.5 (23.0)	22.4 (24.6)	31.2 (29.9)	22.2 (26.9)	23.5 -	26.8 (29.5)
TICULATED VEHICLES								
axle 	12.0	21.6 (22.9)	21.0 (21.5)	20.8 (23.8)	23.0 (22.9)	20.9 (22.0)	21.0 -	23.4 (25.7)
axle (normal tandem) 	12.0	27.2 (28.5)	26.1 (26.6)	25.9 (29.4)	31.2 (31.1)	25.9 (30.6)	27.1 -	30.4 (33.4)
axle (spread tandem) 	13.0	30.0 (31.2)	29.2 (29.7)	28.7 (32.7)	31.2 (31.1)	25.9 (30.6)	29.2 -	33.8 (37.2)
axle (normal tandem) 	13.8	32.8 (34.0)	31.2 (31.7)	31.0 (35.0)	39.4 (39.3)	30.9 (39.2)	33.2 -	37.4 (41.1)
axle (spread tandem) 	13.8	33.5 (34.0)	34.2 (34.7)	31.0 (38.3)	39.4 (39.3)	30.9 (39.2)	33.3 -	40.8 (44.9)
axle 	13.8	35.9 (36.4)	34.2 (34.7)	33.1 (39.6)	39.4 (39.3)	30.9 (39.2)	35.6 -	40.8 (44.9)
UCK - TRAILER								
axle 	15.3	35.0 (35.5)	34.3 (34.8)	34.0 (38.3)	39.4 (39.3)	33.9 (39.2)	34.7 -	39.4 (43.3)

:
igures without brackets denote the maximum mass given by the statutory limits.
igures in brackets denote the maximum mass at which these vehicles would be permitted to operate on the road system.

Source: NAASRA (1975) A Study of the Economics of Road Vehicle Limits. Summary and Recommendations. Study Team Report - R3 October, 1975

APPENDIX 2.1

Sheet 1 of 2

MATHEMATICAL FORMULATIONS FOR ROAD PLANNING STUDIES

Reference Larsson (1959)

Larsson (1959) develops Equation (2) page 70 as follows:

Using as a basis the schematic diagram Figure 2.2 as representing the layout of the roads Larsson assumes -

1. That the cost of transportation, loading and unloading in the forest area, t, is a quantity which is dependent on the bee-line skidding distance to the motor truck haul road. That is t expressed as a cost per unit length can be written as a function of U the skidding distance

   i.e. $t = f_t\ (u)$

2. The road cost, y, is a quantity which is dependent on the volume of timber transported, w

   i.e. $y = f_y\ (w)$

It follows that the cost of transportation on an internal forest road, z, will vary with the road standard and therefore the road cost, y.

i.e. $z = f_z\ (y)$

Thus the cost of transportation and loading in the forest area

$$= 2.\ p.\ b.\ \int_o^a f_t(u).\ u.\ du \qquad (2.1.1)$$

The cost of loading and unloading of motor trucks

$$= 2.\ p.b.a.L \qquad (2.1.2)$$

(L = cost per cubic metre)

The cost of the road

$$= \int_o^b f_y\ (w).\ dv \qquad (2.1.3)$$

(v = distance along road)

The cost of transportation on the road

$$= 2.\ p.\ a \int_o^b f_z\ (y).\ v.\ dv \qquad (2.1.4)$$

The total cost of transportation is

$$C_t = (2.1.1) + (2.1.2) + (2.1.3) + (2.1.4)$$

It is required to find the road spacing at which the cost of transportation per cubic metre is a minimum. Differentiation of the expression C_t requires the general character of the functions, f_t (u) and f_z (y) to be formulated. This can only be done by empirical investigations or by making 'reasonable assumptions'.

APPENDIX 2.2

Sheet 1 of 2

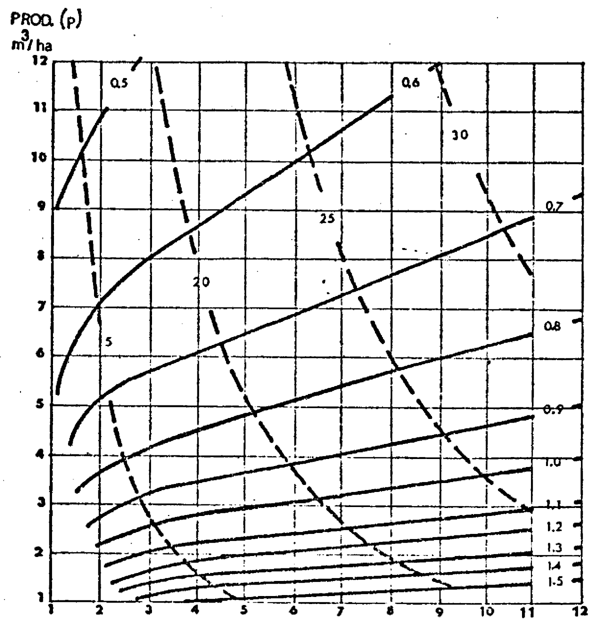


Figure 6, Larsson and Rydstern (1968) page 27.

Represents the optimum range of the road (full-line curves) in kilometres and the optimum road standard (dash-line curves), expressed in terms of the average speed of transportation, in kilometres per hour. The input data required are the length of the road (b) and the average annual production (p).

It must be noted that the figure is specific to the relationships assumed by Larsson and Rydstern (see Appendix 2.1).

APPENDIX 2.2

Sheet 2 of 2

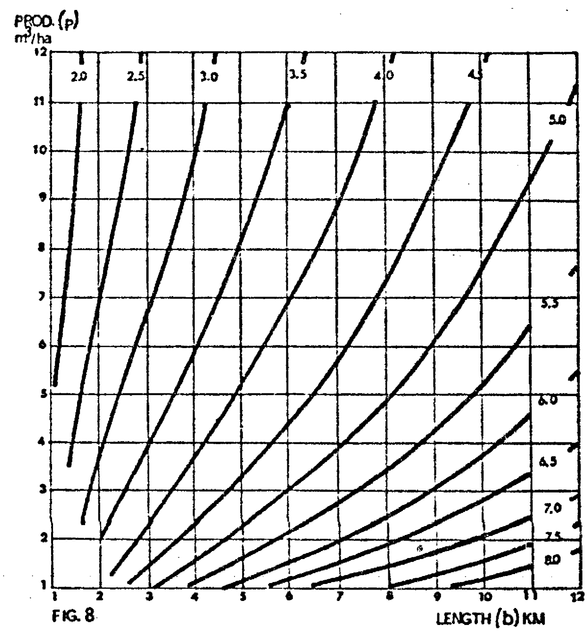


FIG. 8

Figure 8, Larsson and Rydstern (1968) page 28.

Represents the optimum sum of the cost of roads and the cost of transportation as a function of the average annual production (p) and the length of the road.

It must be noted that the figure is specific to the relationships assumed by Larsson and Rydstern (see Appendix 2.1).

APPENDIX 2.3

ANALYSIS OF LOSSES DUE TO NON-OPTIMUM ROAD SPACINGS
(After Larsson (1959) page 70)

It was assumed by Larsson that the optimum range of roads is a, but that topographic conditions or other circumstances necessitate the use of a different range of roads a_1.

The road standard is supposed to be adapted to the latter range of roads (a_1).

The results of the magnitude of the increase in the sum of the costs of roads and costs of transportation per cubic metre caused by a change in the range of the roads is shown in the Table 2.3.1 below.

Table 2.3.1 Increase in costs (D_a) due to change in the range of the roads from the optimum value.

Average Production m^3/ha	Road Length Km	Increased costs (D_a) as % of Total Costs			
		Increase 20% from optimum	Decrease 20% from optimum	Increase 20% from optimum	Decrease 20% from optimum
3	4	0.9	1.2	3.1	6.1
3	8	0.8	1.1	2.8	5.6
6	4	0.9	1.1	3.0	5.7
6	8	0.8	1.0	2.8	5.2
9	3	0.9	1.3	2.9	6.2
9	6	0.8	1.1	2.9	5.0

APPENDIX 2.4

ANALYSIS OF LOSSES DUE TO NON-OPTIMUM ROAD STANDARD (After Larsson (1959) page 73).

While the standard of a forest road from a landing may be gradually adapted to an increasing volume of traffic the standard may nevertheless be too high or too low throughout the road, that is a small change in the cost of the road (increase or decrease) would not be offset by the same arithmetic change (decrease or increase) in the costs of transportation.

Larsson examined the effects of such changes from calculated optimum values and the results are shown in Table 2.4.1 below. It was assumed that the road spacing was adapted to the change in the road standard.

Table 2.4.1 Increase in costs (D_s) due to change in cost of roads in relation to optimum value.

Average Production m^3/ha	Road Length Km	D_s as Per Cent of Total Transportation Costs 20% Increase from optimum	20% Decrease from optimum	40% Increase from optimum	40% Decrease from optimum
3	4	1.0	1.5	3.7	8.1
3	8	0.9	1.5	3.5	8.1
6	4	0.9	1.5	3.6	8.2
6	8	0.9	1.4	3.4	7.8
9	3	0.9	1.5	3.6	8.3
9	6	0.6	1.4	3.5	7.9

APPENDIX 2.5
Sheet 1 of 2

ANALYSIS OF LOSSES DUE TO INADEQUATE ADPTION
OF ROAD STANDARDS TO TRAFFIC VOLUME
(After Larsson (1959) page 76).

Larsson (*op.cit.)* assumed in the development of the theoretical analysis that the volume of traffic along the forest road varied from inappreciable at the initial point of the road to a maximum value at the point of intersection with the highway or arterial road. On the basis that in practice forest roads may be constructed with relatively uniform standard from beginning to end, that is an 'inadequate adaption' Larsson (*op.cit.*) examined for the losses when there was no adaption of the standard to the traffic volume. That is the standard remained unchanged throughout the length of the road. The basis for comparison of 'inadequate adaption' was the 'optimum' case where there was adaption of the standard. The total cost of the length of the road is the same for the 'optimum' and the 'inadequate adaption' and the losses if any accrue from increased transportation costs along the road.

The results are shown in Table 2.5.1 which are of course related to the specific data of the Larsson (*op.cit.*) analysis.

Table 2.5.1 Increase in costs (D_t) due to non-adaption of the road standard to variation in traffic volume in the longitudinal direction of the road.

Average Production m^3/ha	Length of Road Km	Increase in Costs (D_t) Per Cent of Total Transportation Costs	Road Costs
3	4	1.4	4.3
3	8	2.1	7.2
6	4	1.7	5.3
6	8	2.3	8.2
9	3	1.7	5.1
9	6	2.3	8.0

APPENDIX 3.1

Sheet 1 of 3

AUSTRALIAN NATIONAL UNIVERSITY

DEPARTMENT OF FORESTRY

THESIS PROJECT - U TIN OHN

PROFORMA NO. 1 - SNIGGING

RESERVE

COMPARTMENT NO.

YEAR SNIGGING PERIOD

REMARKS

VOLUME OF TIMBER

	NO. LOGS	CUBIC TONS
Elephants		
Buffaloes		
Skidders		
Total		

Size of Logs

ITEM	ELEPHANTS	BUFFALOES	SKIDDERS	MEN
Number of Skidding Powers				
Working Period (days)				
Snigging Distance				
Snigging Cost				

APPENDIX 3.1
Sheet 2 of 3

AUSTRALIAN NATIONAL UNIVERSITY

DEPARTMENT OF FORESTRY

THESIS PROJECT - U TIN OHN

PROFORMA NO. 2 - TRUCKING

RESERVE

COMPARTMENT NO.

YEAR TRUCKING PERIOD

REMARKS

NO. LANDINGS.

ROADING COSTS

	Section 1 (A)		Section 2 (B)		Section 3 (C)	
	Length	Cost	Length	Cost	Length	Cost
Construction						
Maintenance (Annual)						

HAUL DISTANCE

VOLUME	LENGTH			VOLUME	LENGTH		
	a	b	c		a	b	c

LOADING COSTS

VOLUME	COST	VOLUME	COST	VOLUME	COST

TRUCKS	Type	Number	Loads	Truck Days.
Departmental				
Private				

HAUL COSTS

Departmental

Private

APPENDIX 3.1

Sheet 3 of 3

AUSTRALIAN NATIONAL UNIVERSITY

DEPARTMENT OF FORESTRY

THESIS PROJECT - U TIN OHN

PROFORMA NO. 3 - FELLING

RESERVE

COMPARTMENT NO.

YEAR

REMARKS

VOLUME TIMBER

METHOD	NO. OF LOGS	CUBIC TONS
Crosscut Saw		
Chain Saw		
Total		

FELLING POWER

METHOD	NUMBER	NUMBER MEN
Crosscut Saw		
Chain Saw		

WORKING PERIOD	Period	Total No. Days.
Crosscut Saw		
Chain Saw		

APPENDIX 3.2

SUMMARY OF LOGGING COSTS FOR COMPARTMENTS IN PROME AGENCY - BURMA (1)

Compartment No.	Skidding Cost Kyats/m^3	Roading Cost Kyats/Km	Road Haulage Cost Kyats/m^3/Km
41	23.27	1456.79	0.4904
42	27.70	1456.79	0.4751
43	26.04	1456.79	0.4607
44	24.38	1456.79	0.4607
22	38.78	1503.67	0.4904
23	36.57	1502.52	0.4904
25	36.57	1503.67	0.5153
26	37.67	1503.67	0.5153
29	37.67	936.14	0.5242
30	43.21	936.14	0.5242
36	37.67	1503.67	0.4904
8	21.88	1044.73	0.8585
9	27.70	1044.73	0.8585
10	21.61	1044.73	0.7870
11	21.61	1044.73	0.8395
12	21.61	1044.73	0.7555
13	22.16	1044.73	0.6093

(1) Compiled from information compiled on the pro-formas shown in Appendix 3.1.

THEORETICAL FORMULATIONS FOR DEFINING THE MAXIMUM DIRECT SKIDDING DISTRANCE

(After Matthews (1942))

It has been shown (Section 2.2) that Equation (2) page 70, and below, provides for the calculation of the optimum spacing of roads for the layout represented schematically in Figure 2.2 page 69.

$$a = \sqrt{\frac{y}{p\ t_r}} \qquad 3.3.1 \text{ Equation (2)}$$

a = range of roads (that is half the distance between roads)

y = cost of road construction and maintenance per unit length

p = average production in cubic metres per unit area

t_r = variable cost of skidding per cubic metre per unit length

If the lateral roads shown in Figure 2.2 are not constructed then, for a width of forest say D from an existing road, the average skidding distance would be D/2 and the average skidding cost therefore D/2. t_r per cubic metre.

If this average cost per cubic metre for direct skidding is greater than the average cost of extraction using lateral roads at their optimum spacing then roads should be constructed.

The cost of extraction if lateral roads are constructed is calculated as follows for a block a distance 'a' either side of a lateral road in Figure 2.2

The cost of road per unit volume $= \frac{b.y}{2apb}$

Variable cost of snigging per unit volume (average) $= t_r.\frac{a}{2}$

Average cost of extraction per unit volume

$$= \frac{b.y}{2.a.p.b.} + t_r.\frac{a}{2}$$

If the roads are constructed at optimal spacing, that is in accordance with Equation 3.3.1, then the average cost of extraction per unit volume becomes by substituting for y from 3.3.1

$$\frac{a^2.p.t_r}{2a.p} + t_r.\frac{a}{2}$$

$$= t_r.\frac{a}{2} + t_r.\frac{a}{2}$$

i.e. $t_r.a$

Whenever $t_r.\frac{D}{2}$ the average cost of direct skidding for a width D is greater than $t_r.a$ lateral roads should be built. That is when D is greater than 2a, the spacing of the roads in Figure 2.2.

APPENDIX 3.4

STATISTICAL PARAMETERS ASSOCIATED WITH SYNTHETIC SKIDDING DISTANCES
(for 100 m gridlines)

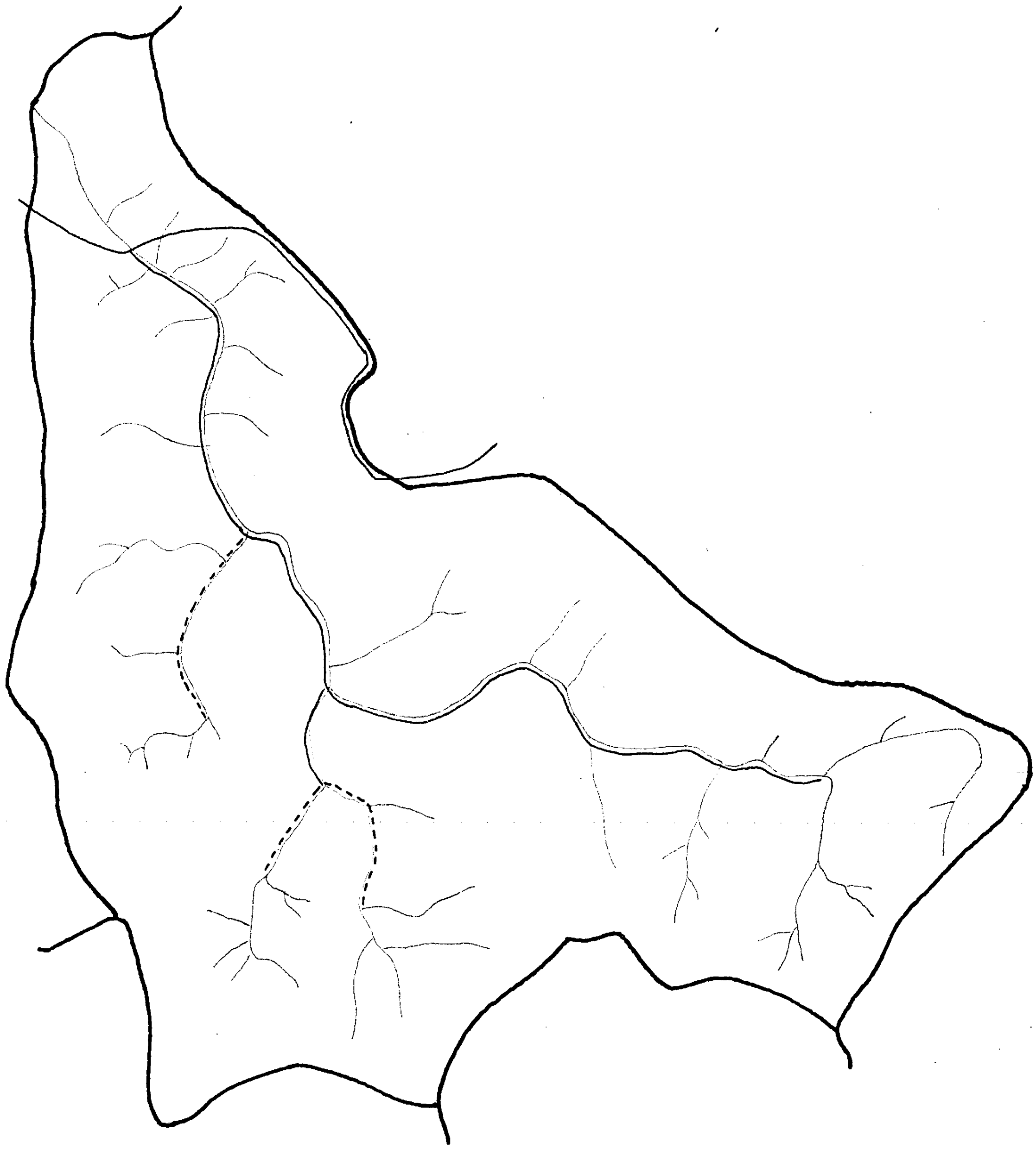
Compartment No.	Mean[2] Scaled Distance	Standard Error	Standard Deviation	Variance	Kurtosis	Skewness
41	0.601	0.030	0.483	0.234	-0.279	0.743
42	0.822	0.044	0.859	0.737	2.808	1.723
43	0.675	0.033	0.550	0.303	0.543	0.958
44	0.719	0.031	0.582	0.279	-0.276	0.659
22	0.897	0.041	0.688	0.474	-0.659	0.532
23	1.019	0.044	0.775	0.601	0.600	0.931
25	0.850	0.037	0.606	0.368	-0.051	0.708
26	0.988	0.044	0.662	0.438	-1.065	0.222
29	0.576	0.029	0.480	0.231	0.934	1.030
30	1.646	0.065	1.148	1.318	-1.105	0.291
36	1.469	0.040	0.958	0.917	-0.919	0.250
8	0.548	0.026	0.419	0.176	-0.541	0.566
9	1.651	0.083	1.159	1.343	-1.085	0.261
10	2.210	0.084	1.048	1.098	-0.878	-0.387
11	0.927	0.053	0.761	0.579	-0.090	0.860
12	0.469	0.021	0.373	0.139	-0.476	0.604
23	0.650	0.021	0.517	0.268	0.125	0.848

(1) The statistical calculations are based on a scaled distance.

(2) The mean synthetic skidding distance is 400 x mean scaled distance. The mean synthetic skidding distances are shown in Table 3.2

Compartment 41

APPENDIX 3.5
Sheet 1 of 9



Scale 1:16000

LEGEND

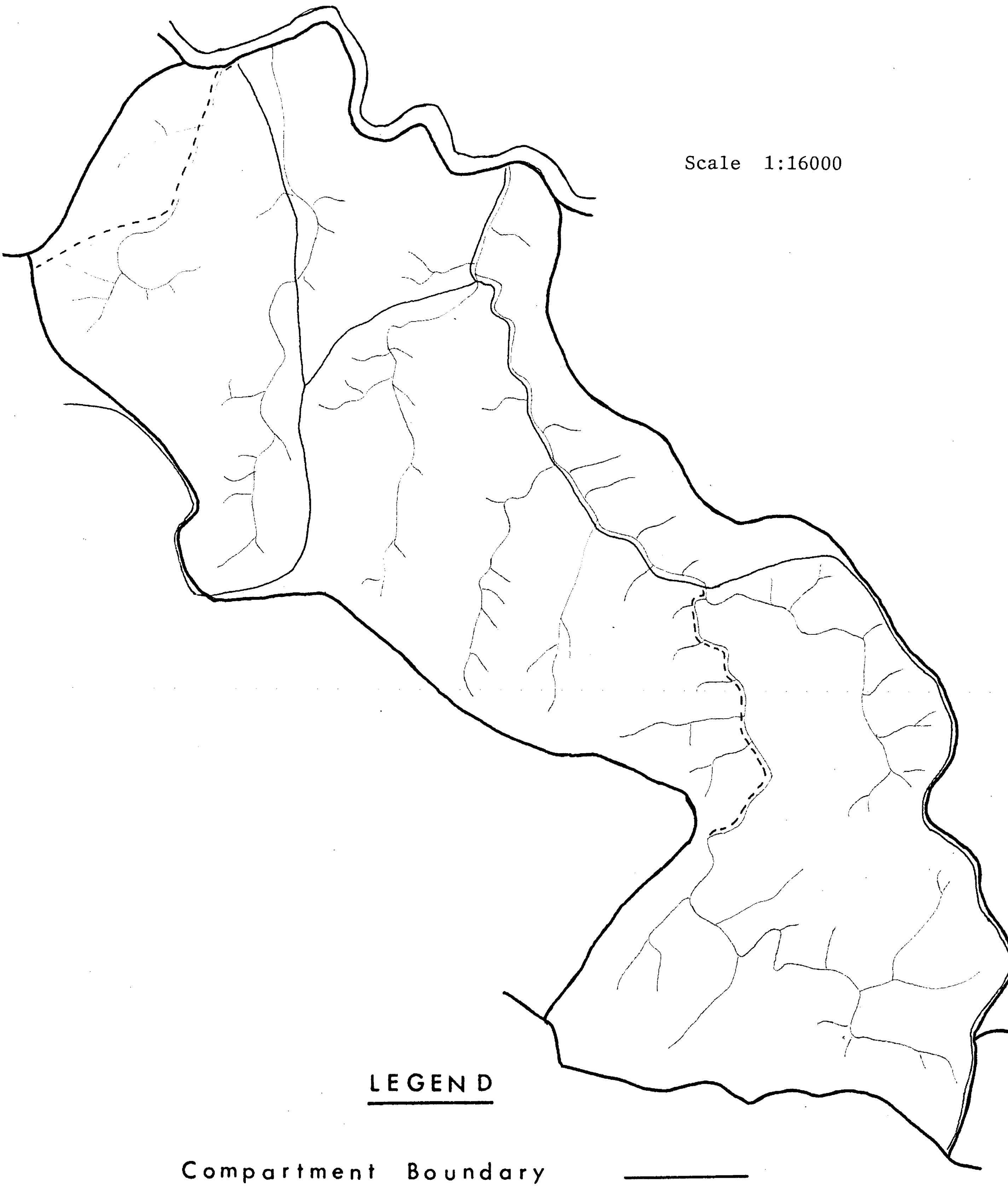
Compartment Boundary
Streams
Existing Road
Proposed Road

Compartment 42

APPENDIX 3.6

Sheet 2 of 9

Scale 1:16000



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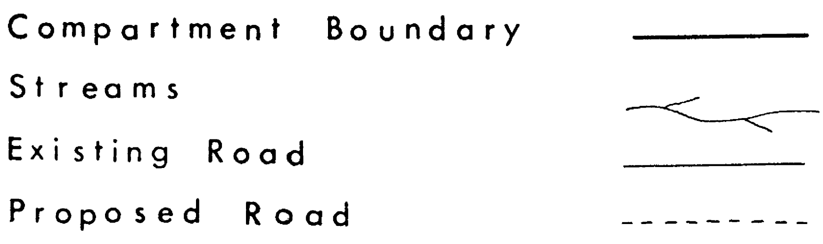
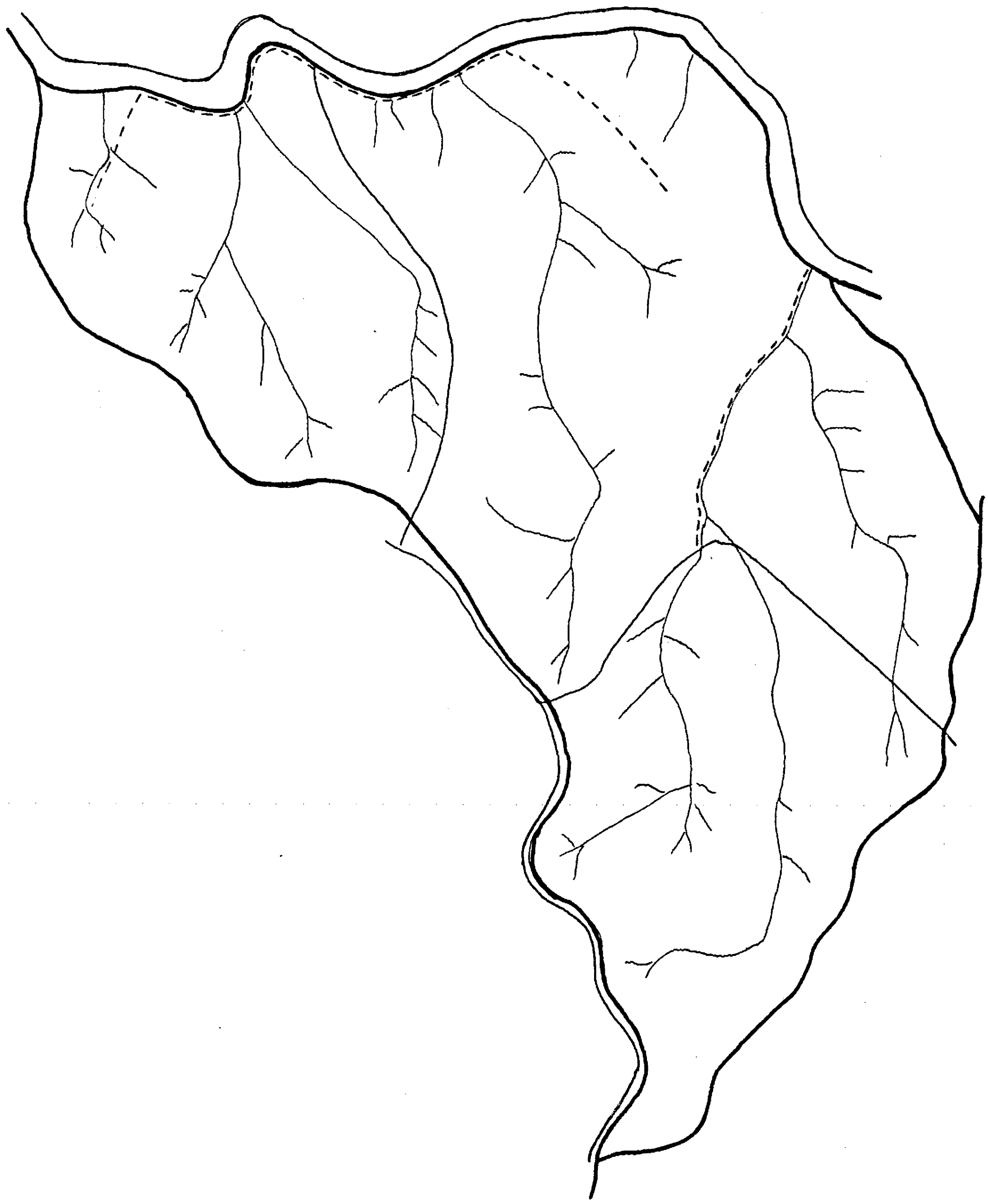


Compartment 43

APPENDIX 3.5
Sheet 3 of 9



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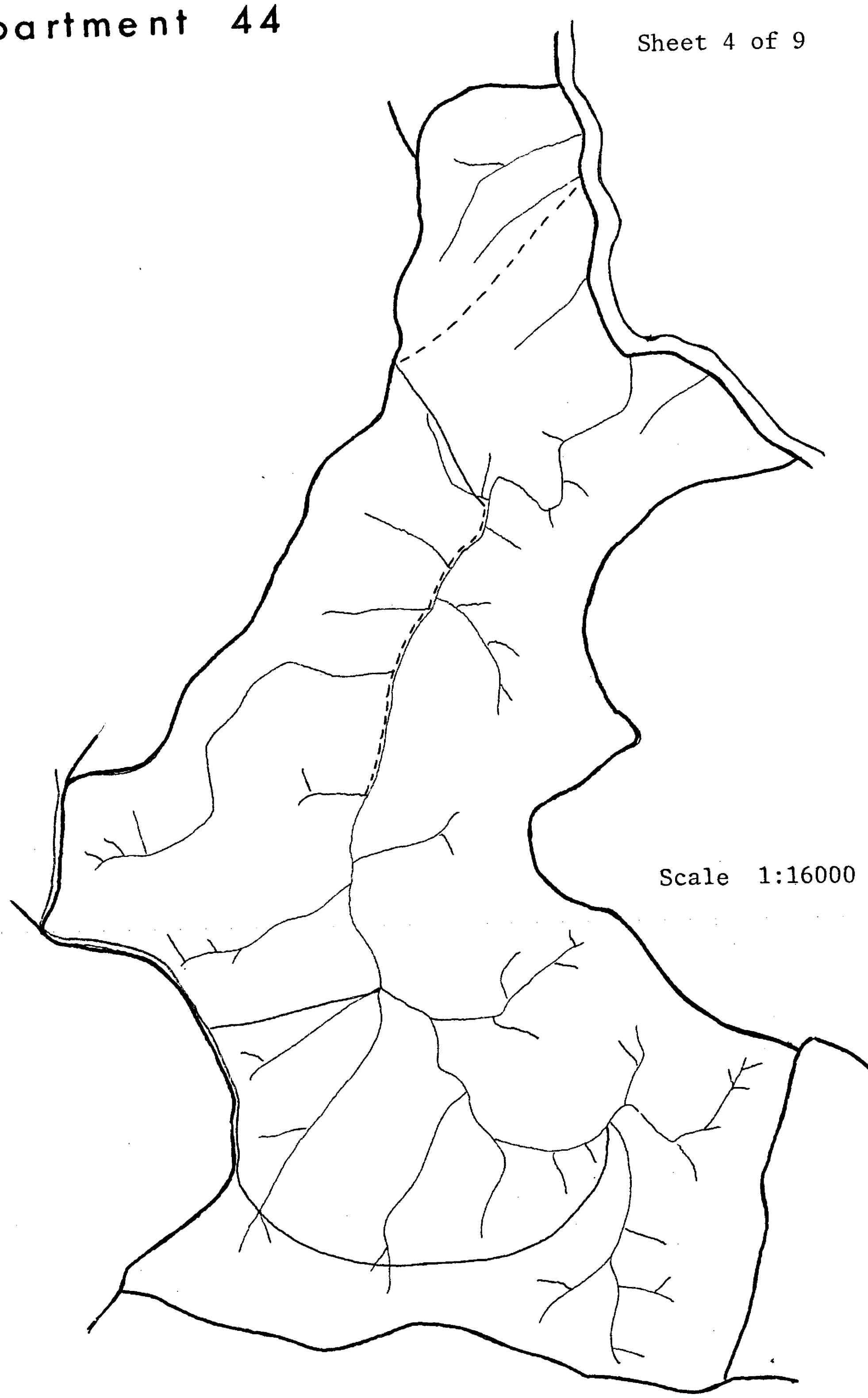
LEGEND

Compartment Boundary
Streams
Existing Road
Proposed Road

Compartment 44



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LEGEND

Compartment Boundary

Streams

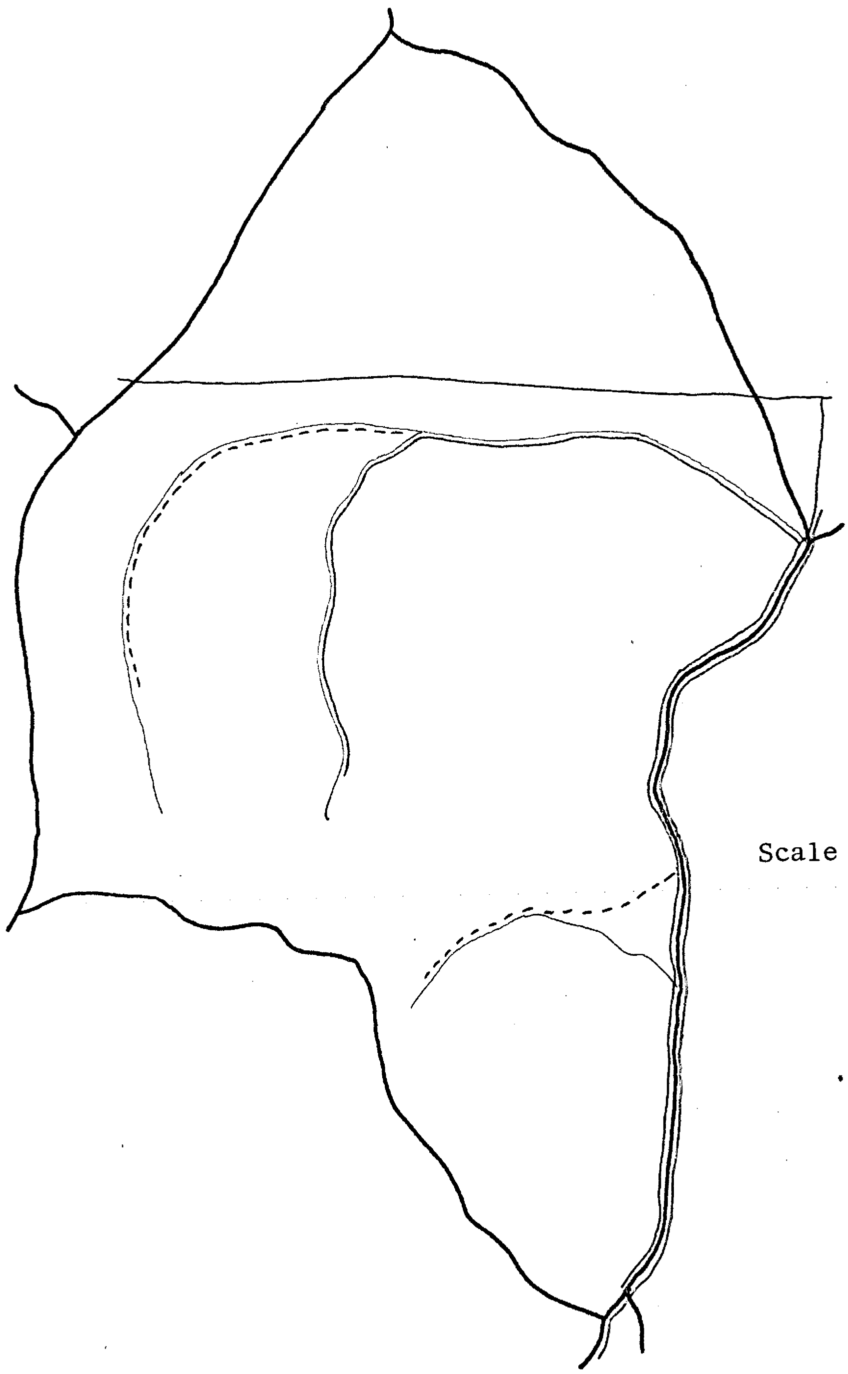
Existing Road

Proposed Road

APPENDIX 3.5

Sheet 5 of 9

Compartment 8



Scale 1:16000

LEGEND

Compartment Boundary

Streams

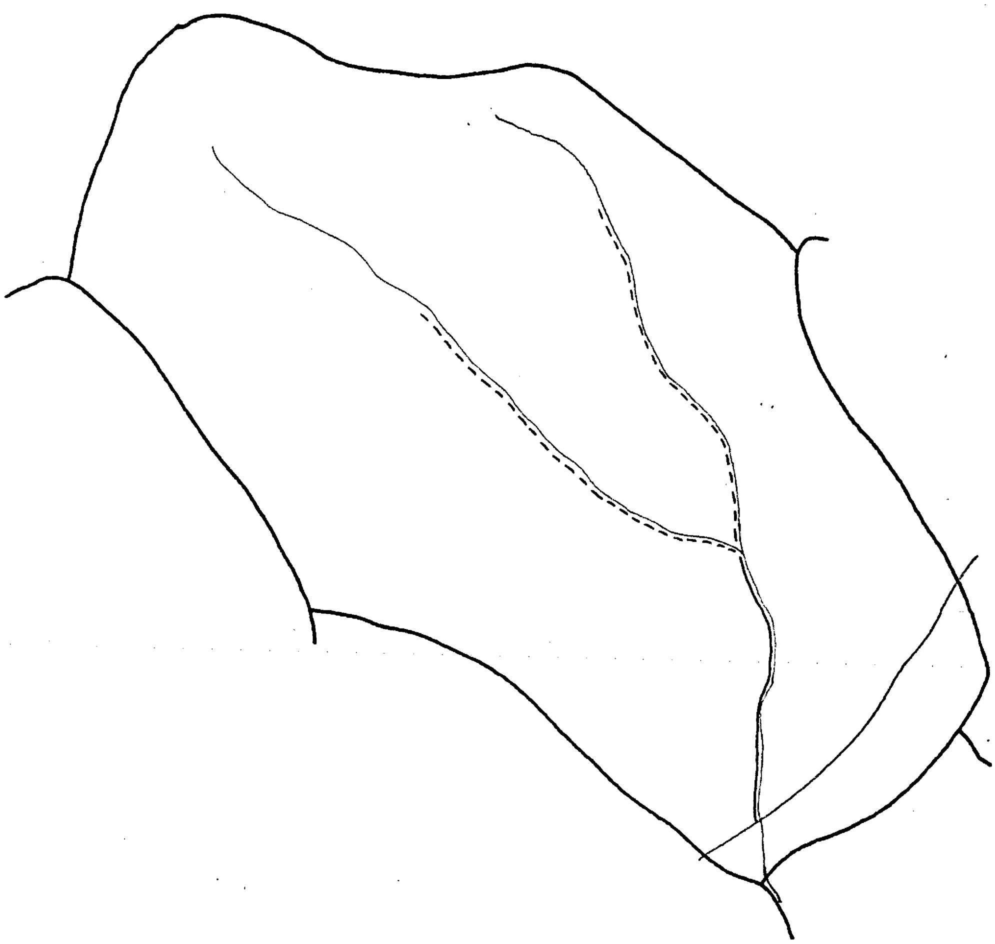
Existing Road

Proposed Road

Compartment 9

APPENDIX 3.5

Sheet 6 of 9



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LEGEND

Compartment Boundary

Streams

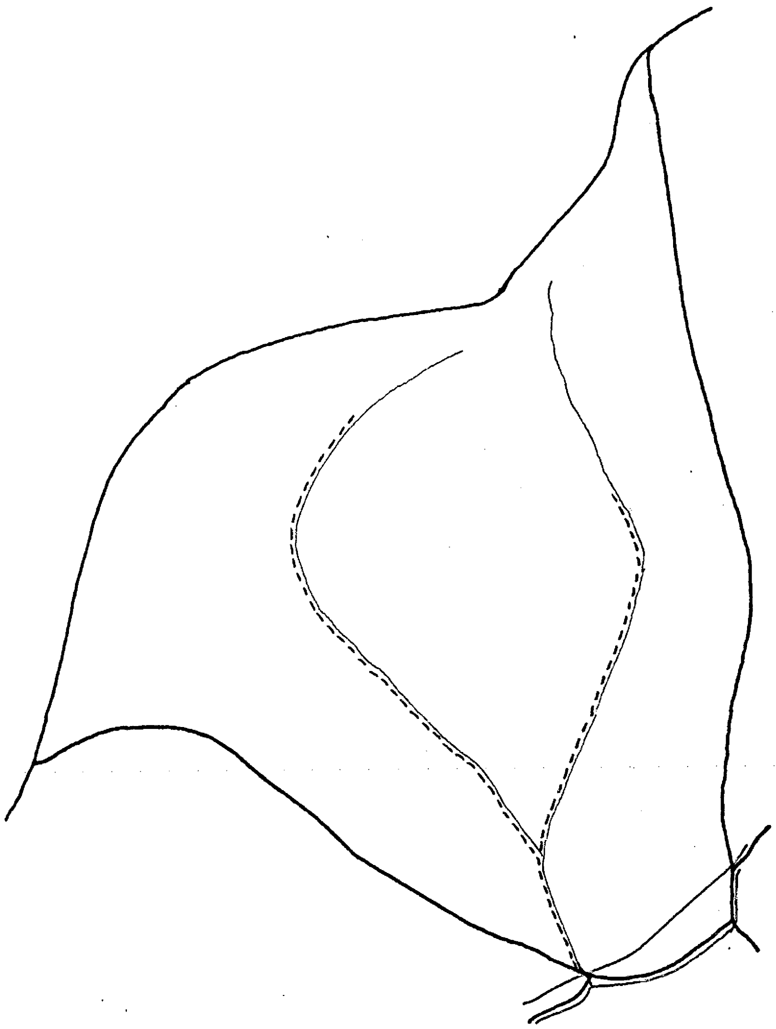
Existing Road

Proposed Road

Compartment 10

APPENDIX 3.5

Sheet 7 of 9



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LEGEND

Compartment Boundary

Streams

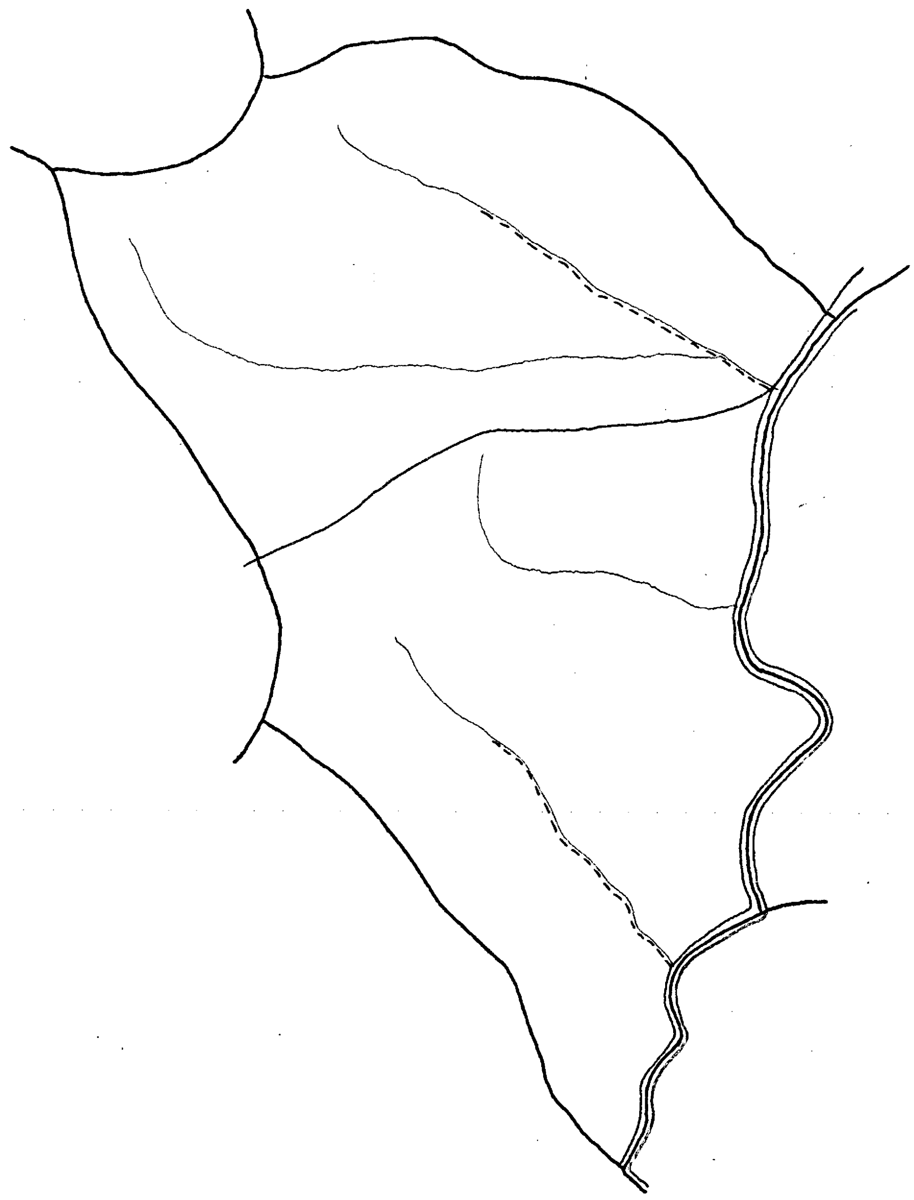
Existing Road

Proposed Road

Compartment 11

APPENDIX 3.5

Sheet 8 of 9



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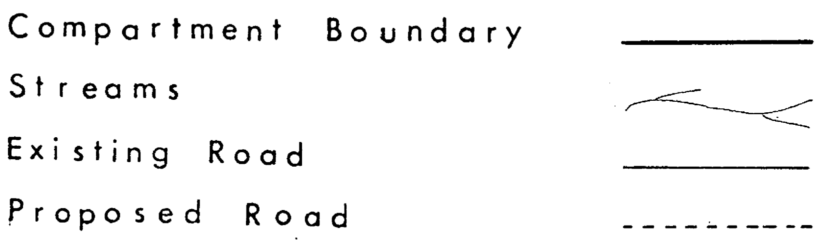
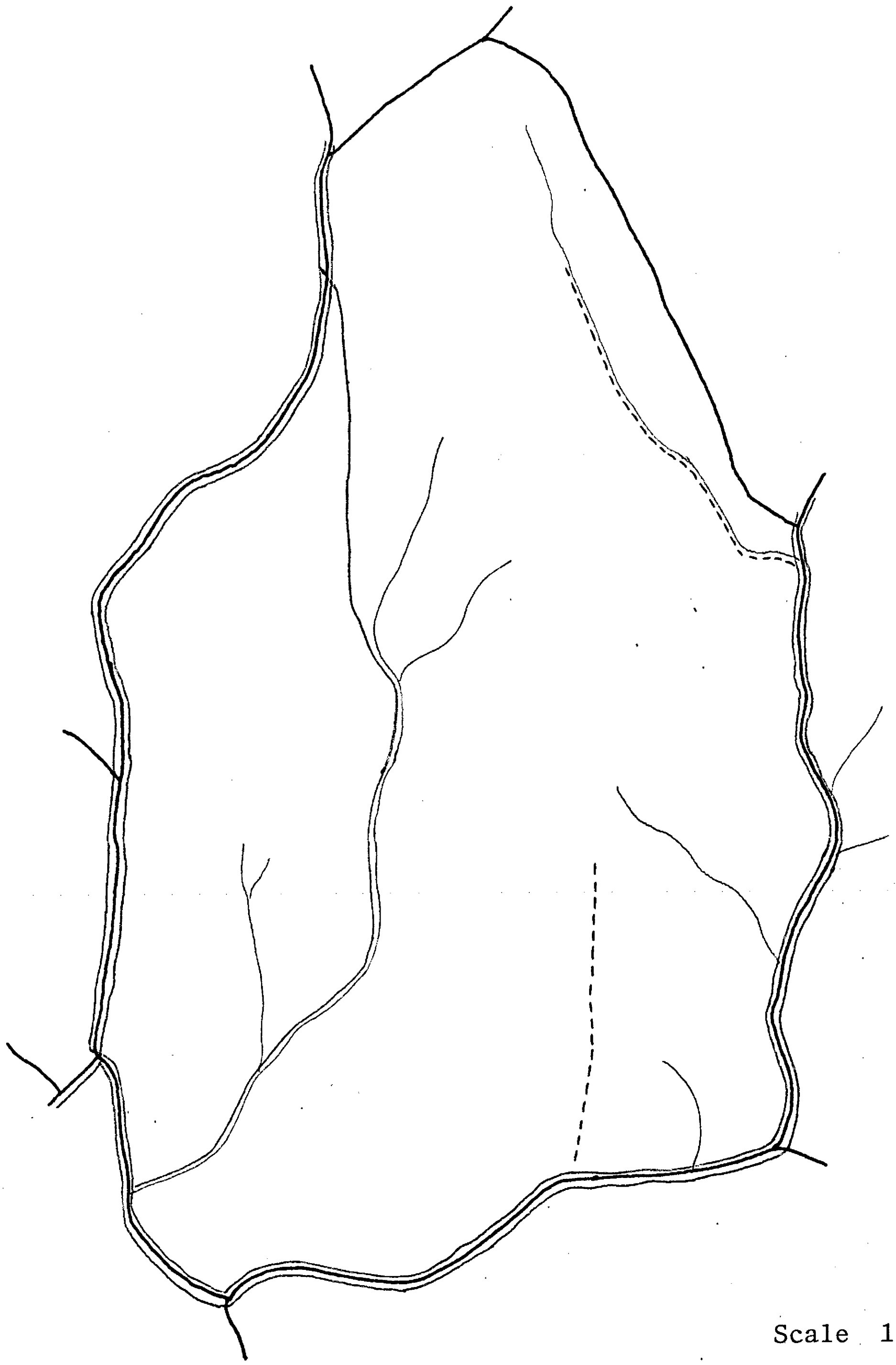


Compartment 12



Scale 1:16000

LEGEND

Compartment Boundary

Streams

Existing Road

Proposed Road

APPENDIX 3.6

Sheet 1 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 41

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed (1) Skidding Cost %	Estimated Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	5535	1808	-	53100(2)	60443	-
Trial 1	6235	1794	0	50002	58031	2412
			30	50931	58960	1483
			50	51551	59580	863
			60	51861	59890	553
			70	52171	60200	243
Trial 2	6701	1857	0	44913	53471	6972
			30	47370	55898	4545
			50	49007	57565	2878
			60	49826	58384	2059
			70	50644	59209	1241
Trial 3	7167	1865	0	41152	50184	10259
			30	44736	53768	6675
			50	47126	56158	4285
			60	48321	57353	3090
			70	49516	58548	1895

(1) Ratios shown are fixed skidding costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6

Sheet 2 of 9

ROAD,HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 42

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed (1) Skidding Cost %	Estimated Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	9790	3532	-	65880 (2)	79202	-
Trial 1	11072	3621	0	64078	78771	431
			30	64618	79311	-109
			50	64979	79632	-470
			60	65159	79852	-650
			70	65339	80032	-830
Trial 2	11013	3654	0	49260	63837	15365
			30	54246	68828	10379
			50	57570	72147	7055
			60	59232	73809	5393
			70	60894	75471	3731
Trial 3	12295	3657	0	45655	61607	17595
			30	51723	67675	11527
			50	55768	71720	7482
			60	57790	73742	5460
			70	59813	75765	3437

(1) Ratios shown are fixed skidding costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6

Sheet 3 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 43

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed (1) Skidding Cost %	Estimated Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	5885	714	-	35915 (2)	42514	-
Trial 1	7050	781	0	33403	41234	1280
			30	34157	41988	526
			50	34659	42490	24
			60	34910	42741	-227
			70	35162	42993	-479
Trial 2	8391	996	0	23483	32870	9644
			30	27213	36600	5914
			50	29699	39086	3428
			60	30942	40329	2188
			70	32141	41528	986
Trial 3	9556	1053	0	20917	31526	10988
			30	25455	36064	6450
			50	28443	39052	3462
			60	29937	40546	1968
			70	31432	42041	473

(1) Ratios shown are fixed skidding costs as % of total skidding costs

(2) Actual recorded skidding costs.

APPENDIX 3.6

Sheet 4 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 44

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed (1) Skidding Cost %	Estimated Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	4895	866	-	40067 (2)	45828	-
Trial 1	5769	868	0	36181	42818	3010
			30	37793	44430	1398
			50	38443	45080	748
			60	38767	45404	424
			70	39092	45729	99
Trial 2	6002	1016	0	32622	39640	6188
			30	34855	41873	3955
			50	36345	43363	2465
			60	37089	44107	1721
			70	37834	44852	976
Trial 3	6876	1027	0	29373	37276	8552
			30	32581	40484	5344
			50	34720	42623	3205
			60	35789	43692	2136
			70	36859	44762	1066

(1) Ratios shown are fixed skidding costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6

Sheet 5 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 8

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed Skidding Cost %	Estimated (1) Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	5474	2509	-	23903 (2)	31886	
Trial 1	6519	2462	0	20041	29022	2864
			30	21200	30181	1705
			50	21972	30953	933
			60	22358	31339	547
			70	22744	31725	161
Trial 2	6101	2244	0	21397	29742	2144
			30	22149	30494	1392
			50	22650	30995	891
			60	22901	31246	640
			70	23151	31496	390
Trial 3	7146	2324	0	17640	27110	4776
			30	19519	28989	2897
			50	20772	30242	1644
			60	21398	30868	1018
			70	22024	31494	392

(1) Ratios shown are fixed costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6
Sheet 6 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 9

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed Skidding Costs %	Estimated (1) Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	1588	906	-	34930 (2)	37424	
Trial 1	2424	1538	0	21699	25661	11763
			30	25668	29630	7794
			50	28314	32276	5148
			60	29638	33600	3824
			70	30961	34923	2501
Trial 2	2507	1602	0	16936	21045	16379
			30	22334	26443	10981
			50	25933	30042	7382
			60	27732	31841	5583
			70	29532	33641	3783
Trial 3	3343	1580	0	13760	18683	18741
			30	20259	25182	12242
			50	24451	29374	8050
			60	26547	31470	5954
			70	28643	33566	3858

(1) Ratios shown are fixed costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6

Sheet 7 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 10

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed Skidding Cost %	Estimated (1) Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	418	188	-	12900 (2)	13506	
Trial 1	1588	478	0	5908	7974	5532
			30	8005	10071	3435
			50	9404	11470	2036
			60	10103	12169	1337
			70	10802	12868	638
Trial 2	1922	590	0	4486	6998	6508
			30	7010	9522	3984
			50	8693	11205	2301
			60	9534	12046	1460
			70	10376	12888	618
Trial 3	2758	553	0	2990	6301	7205
			30	5963	9274	4232
			50	7945	11256	2250
			60	8936	12247	1259
			70	9927	13238	268

(1) Ratios shown are fixed costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6
Sheet 8 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 11

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed Skidding Cost %	Estimated (1) Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	3218	1098	-	18790 (2)	23106	
Trial 1	3845	1121	0	14727	19693	3413
			30	15946	20912	2194
			50	16759	21725	1381
			60	17165	22131	975
			70	17571	22523	583
Trial 2	3970	1187	0	14981	20138	2968
			30	16124	21281	1825
			50	16886	22043	1063
			60	17266	22423	683
			70	17647	22804	302
Trial 3	4597	1327	0	10868	16792	6314
			30	13244	19168	3938
			50	14829	20753	2353
			60	15621	21545	1561
			70	16413	22337	769

(1) Ratios shown are fixed costs as % of total skidding costs

(2) Actual recorded skidding costs

APPENDIX 3.6
Sheet 9 of 9

ROAD, HAULAGE AND SKIDDING COSTS FOR TRIAL ROAD EXTENSIONS

COMPARTMENT 12

Road Layout	Road Costs Kyats	Haulage Cost Kyats	Fixed Skidding Cost %	Estimated (1) Skidding Cost Kyats	Total Cost Kyats	Savings Kyats
Actual	7522	3021	-	49725 (2)	60268	
Trial 1	8232	3465	0	45205	56902	3366
			30	46561	58258	2010
			50	47465	59162	1106
			60	47916	59613	655
			70	48369	60066	202
Trial 2	8358	3106	0	43875	55339	4929
			30	45630	57094	3174
			50	46800	58264	2004
			60	47385	58849	1419
			70	47970	59434	834
Trial 3	9068	3528	0	36430	49026	11242
			30	40419	53015	7253
			50	43077	55673	4595
			60	44407	57003	3265
			70	45736	58332	1936

(1) Ratios shown are fixed costs as % of total skidding costs

(2) Actual recorded skidding costs

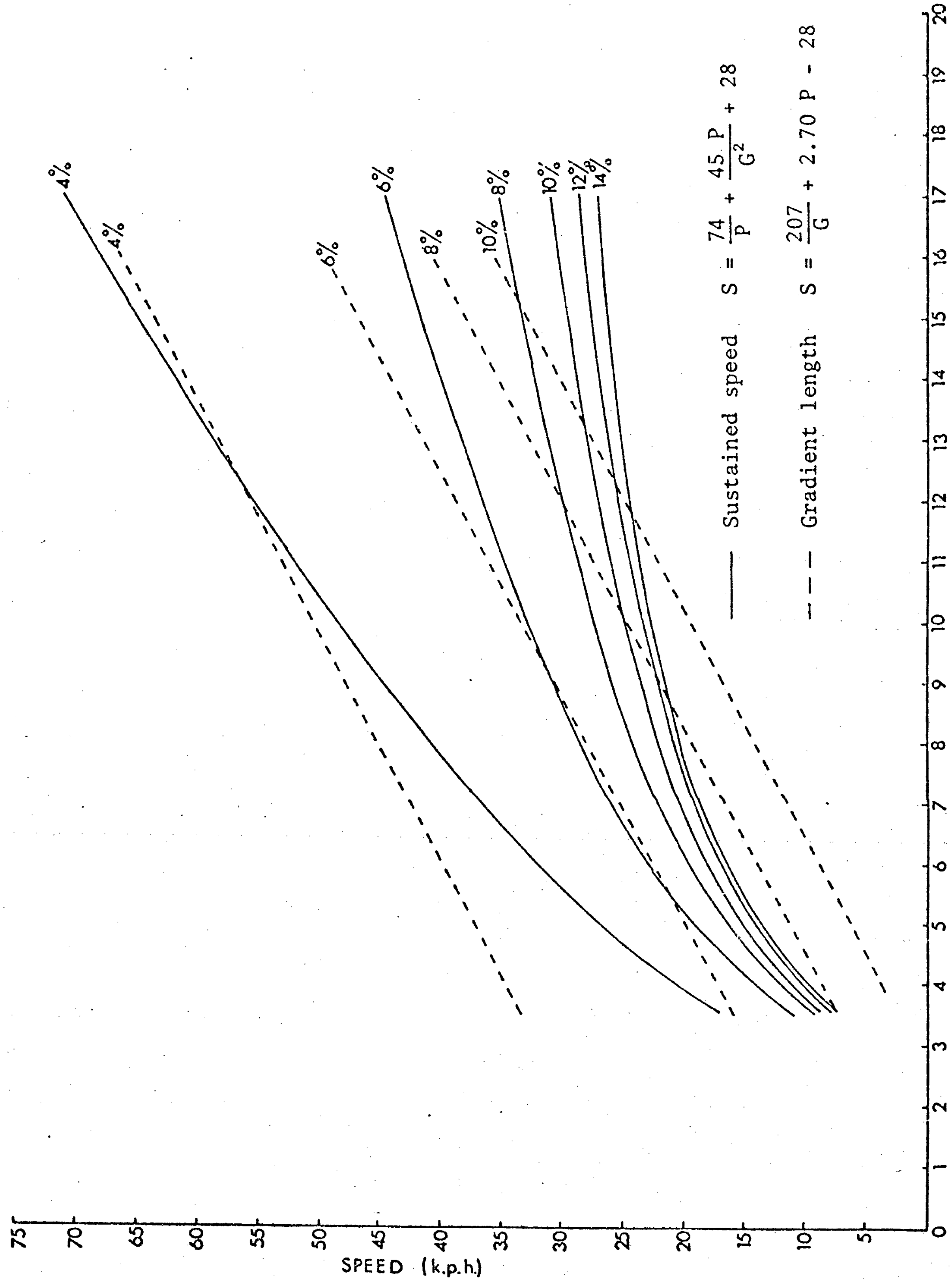


Figure 5.1. Graphical representation of sustained speed and accepted gradient length models.

A gradient Model for Logging Trucks (after Beath (1976))

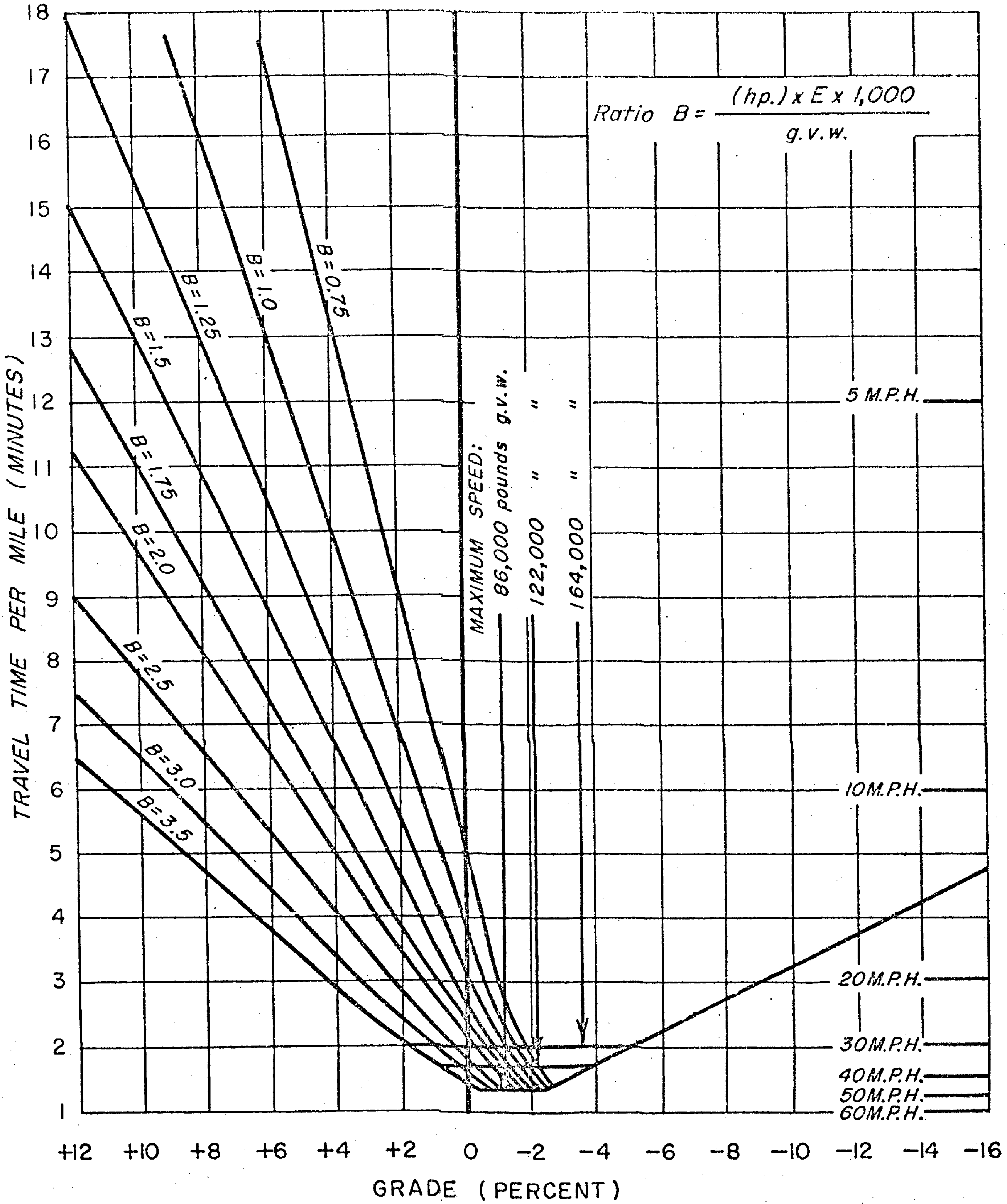


FIGURE 7.—Effect of grade on travel time—loaded trucks, dirt roads (R=0.022).

Effect of Grade on Travel Time
(after Byrne, Nelson and Coogins (1960))

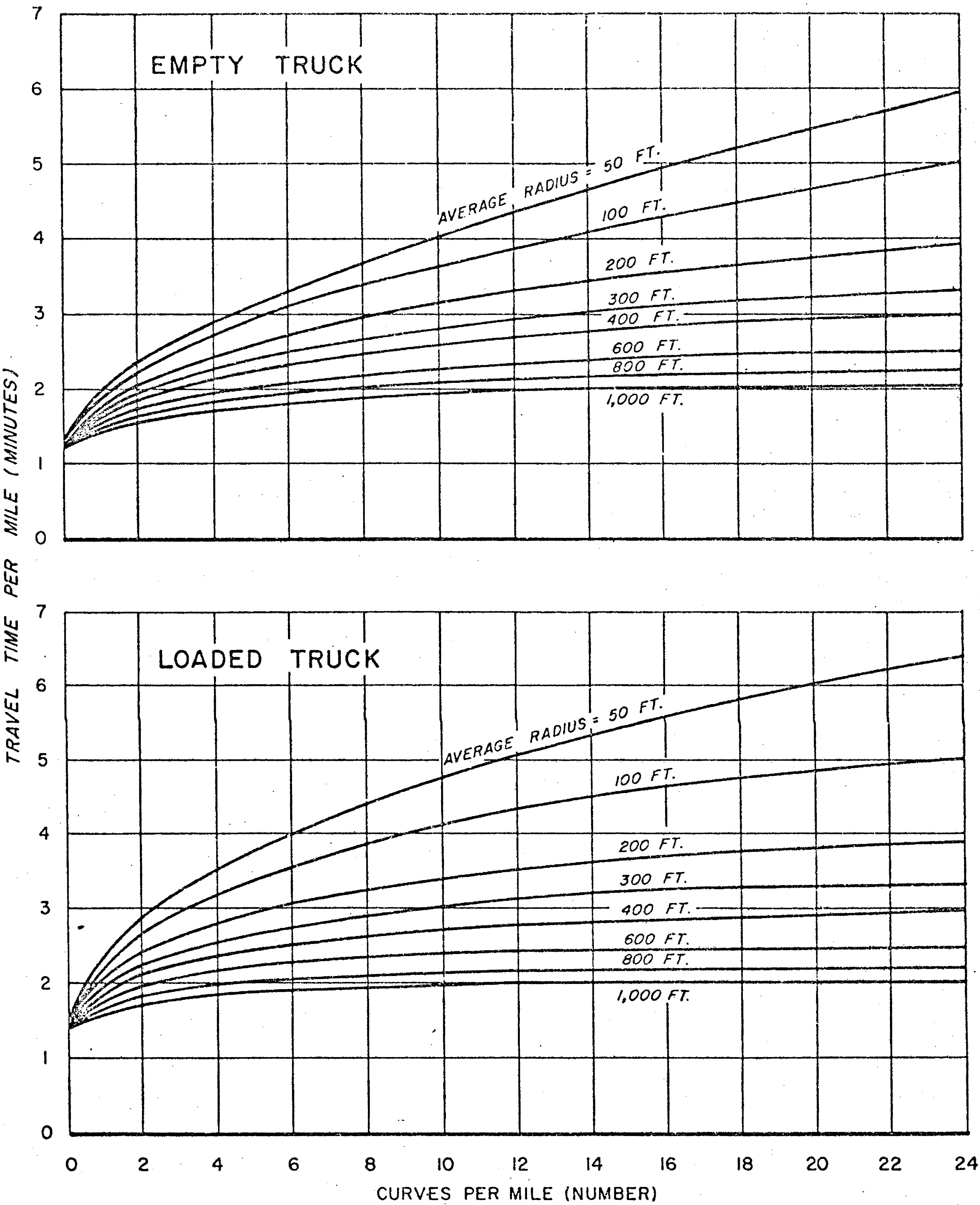
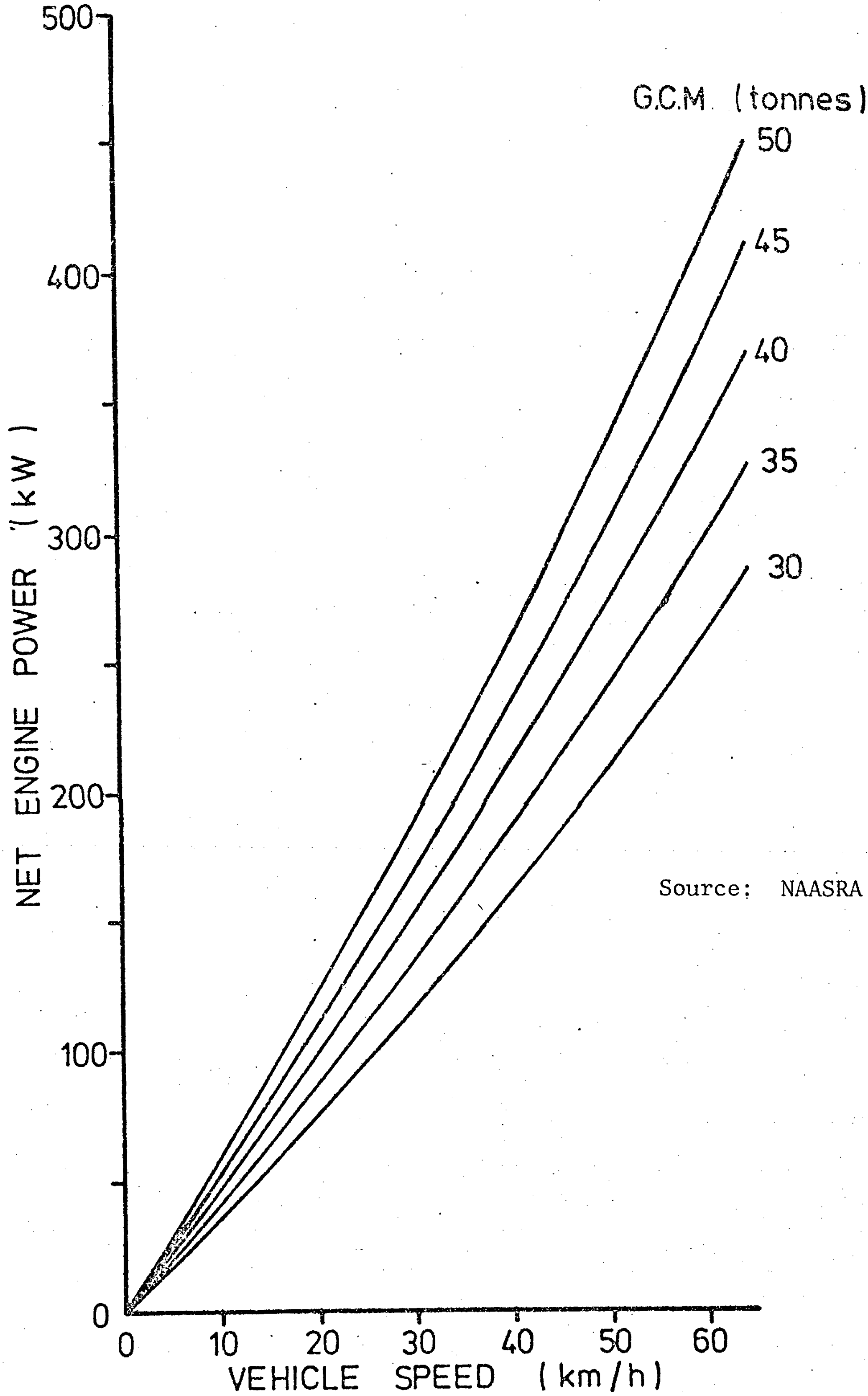


FIGURE 11.—Effect of curvature on travel time—lane-and-one-half roads.

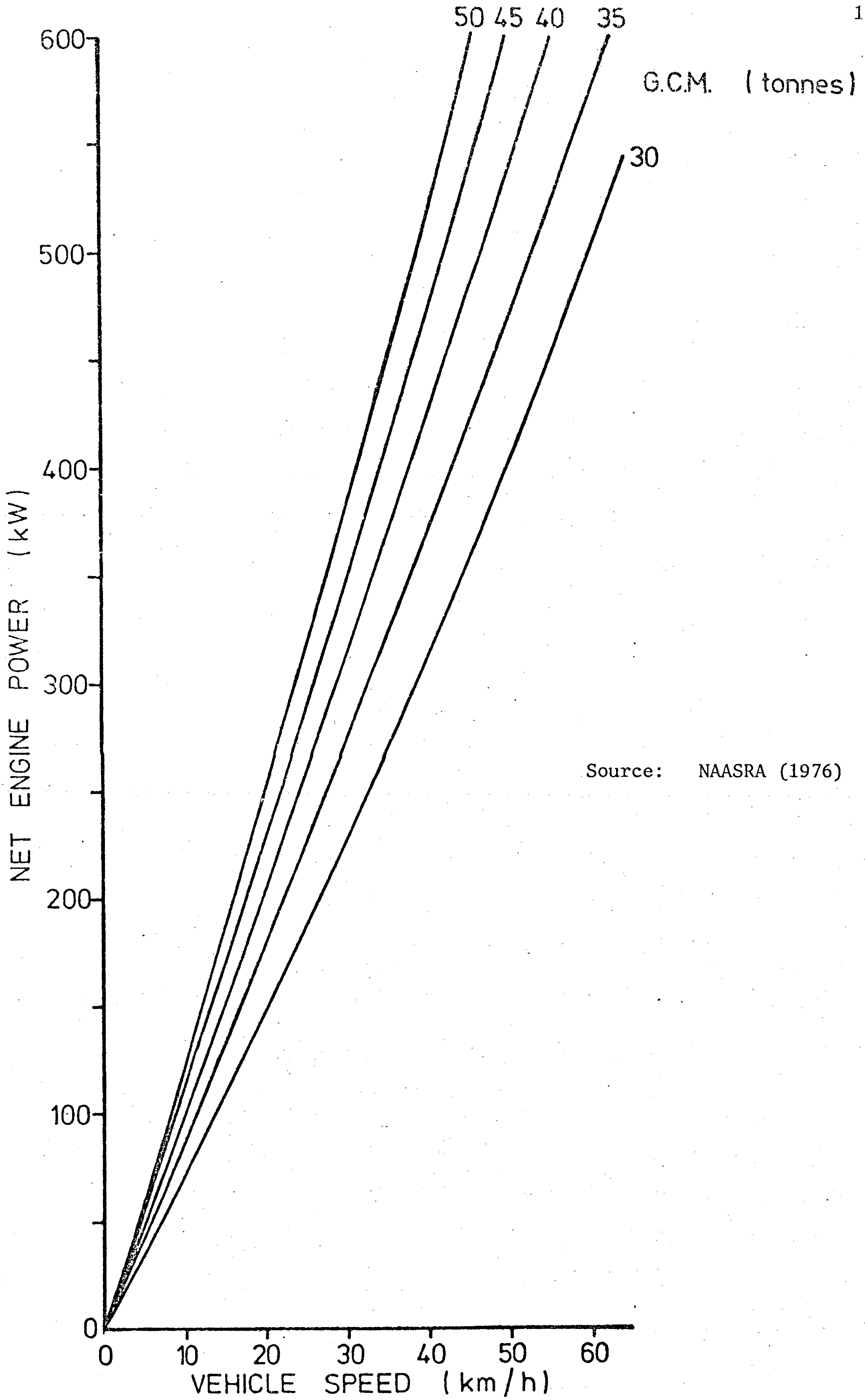
Effect of Curvature on Travel Time

(after Byrne, Nelson and Coogins (1969))



Source: NAASRA (1976)

Estimated Power Requirements for a
Given Road Speed on a 3% Grade



Source: NAASRA (1976)

: Estimated Power Requirements for a Given Road Speed on a 7% Grade

APPENDIX 5.1
Sheet 1 of 2

THEORETICAL FORMULATIONS FOR THE MINIMUM COST FOR THE SUM OF ROAD HAULAGE AND ROAD CONSTRUCTION COSTS

Larsson and Rydstern (1968) assumed that the cost of road transportation varied with the standard of construction of roads (as represented by the cost of construction) as illustrated in Figure 2.11 page 82. They optimized road construction cost and road standards as when an increase in costs of the roads was exactly offset by a decrease in road transportation costs.

Matthews (1942) assumed that the cost of road transportation varied inversely as the standard of construction of the roads. As shown below it is then that the total cost of the road construction and the transportation costs is a minimum when the two costs are equal.

Let x = cost of road construction/unit length.

Then the cost of roads per unit volume of timber, if directly proportional to x, is say ax

Where a = const

And the cost of transportation per unit volume, if inversely proportional to x, is say $b.\frac{1}{x}$

where b = constant

The total cost of the roads and the road transportation per unit volume f(c) is then

$$f(c) = a.x + b.\frac{1}{x}$$

and is a minimum when

$$\frac{d\ f(c)}{dx} = a - \frac{b}{x^2} = 0$$

$$\text{that is when } x = \sqrt{\frac{b}{a}}$$

In turn the separate costs are:

for road construction $\quad a.x = a\sqrt{\frac{b}{a}} = \sqrt{ab}$

for road transport $\quad b.\frac{1}{x} = \frac{b.1}{\sqrt{\frac{b}{a}}} = \sqrt{ab}$

Thus Matthews (1942) criterion of equality is only applicable for the unique inverse relationship assumed.

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